RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

REPORT UPON TRIAL OF THE P.S. "VILLE DE DOUVRES."

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Since their Report of April 1891, the Research Committee on Marine-Engine Trials have been enabled through the kindness of the Belgian Government to carry out a trial on a large paddle-steamer, which in many respects differs considerably from the vessels tested previously.

Steamer.—The steamer tested was the "Ville de Douvres," a paddle-steamer owned by the Belgian Government, and employed by them on the postal service between Ostend and Dover. The Committee are very deeply indebted to the Government and to the officers of their Service du Génie Maritime, especially to M. Allo, Directeur Général de la Marine, M. Delcourt, Ingénieur-en-chef, Directeur, and M. Lecointe, Ingénieur de première classe; also to M. Kraft, Ingénieur-en-chef, and M. Ortmans, Ingénieur, of the Société Cockerill; for the many facilities which they afforded throughout for carrying on the trial, and for the arrangements they kindly made for the accommodation and comfort of all on board. The Committee have also to thank Professor Boulvin of Ghent University, for the trouble he took in obtaining permission from the Belgian Government to test one of their steamers, and for the assistance he rendered during the trial, which originated in a conversation between Professor Boulvin and Mr. Donkin at Ghent.

The "Ville de Douvres," which is driven by feathering paddles, was built and engined by the Société Cockerill, Seraing, Belgium;

"Ville de Douvres."

and was delivered by them to the Belgian Government in February 1890. Between that time and the date of the trial, she made 220 voyages from Ostend to Dover and back. She is a vessel of 271 feet length between perpendiculars, 29 feet breadth, and 15.5 feet depth moulded. Her registered tonnage is—gross 855 tons, under deck 776 tons, and net 495 tons. Her draft during the trial was 8 feet 6½ inches forward, and 9 feet 7 inches aft, or 9 feet 0¾ inch mean; corresponding with a displacement of 1,090 tons.

The trial was made on Tuesday 8th September 1891, upon a run from Ostend over a course round the three light-vessels Nord-Hinder, Outer-Gabbard, and Corton, in the North Sea. Previous to the trial, the vessel had been lying in Ostend harbour, where her machinery had been overhauled. She left her moorings about half-past seven o'clock on the morning of the 8th September, and observations were begun to be taken at 8.0 a.m., but owing to various causes, the trial was not started until 10.0 a.m. It was continued until 7.0 p.m. on the same day, thus lasting for nine hours. The quantity of fuel burnt and other conditions did not allow of its further prolongation. The weather was fine throughout, with smooth sea, so that no difficulty was experienced in taking any of the usual observations. The speed of the engines was fairly constant throughout the trial, with the exception of a period of fourteen minutes from 1.10 to 1.24 p.m., when the engines slowed down a little, owing to temporary failure of the centrifugal circulating-pump, and consequent loss of vacuum in the condenser. The reading of the counter was noted several times during this period, in addition to the readings taken in ordinary course. The valve-gear remained unaltered throughout the trial.

Engines.—The "Ville de Douvres" is fitted with compound inclined surface-condensing engines, working on two cranks at right angles, the high-pressure crank leading. Sections of the cylinders are shown in Plates 16 and 17; and the general arrangement of the engines and boilers in Plate 19. The high-pressure cylinder is situated on the port side of the vessel. The diameters of the cylinders are 50.12 inches and 97.12 inches, by gauges. The piston

“ Ville de Douvres.”

rods are both 8.27 inches diameter, and there are no tail-rods. The stroke of both cylinders is 72 inches. Neither of the cylinders is specially jacketed; the intermediate receiver encircles the high-pressure cylinder. The clearance volumes of the cylinders as given by the makers are, high-pressure 15 per cent., and low-pressure 12 per cent., of the volumes swept through by their respective pistons. The volume of the receiver is 164 cubic feet, or 1.76 times the volume of the high-pressure cylinder and clearance. The total area of the interior surface of the receiver is 379 square feet.

The high-pressure cylinder is provided with a pair of piston-valves, and the low-pressure cylinder with a single one. The valve-gear is the Allan link-motion with a variable cut-off of from 50 to 75 per cent. of the stroke. There are two feed-pumps, two air-pumps, and two bilge-pumps, all vertical and single-acting, one of each driven from each of the two cross-heads by bell-crank levers L, Plate 19; and there is one centrifugal circulating-pump C, driven by a separate double-acting vertical engine, taking steam from the main boilers and exhausting into the condenser S. The feed-pumps and bilge-pumps are all 6.69 inches diameter, and the air-pumps are each 32.68 inches diameter. The stroke of all these six pumps is 24.61 inches. The circulating-pump is 34 inches diameter over the blades, and the suction and delivery pipes are each 14.2 inches bore. The circulating-pump engine has one cylinder 10 inches diameter and 10 inches stroke.* The donkey pump D takes steam from the main boilers, and exhausts through a three-way cock either into the atmosphere or into the condenser. During the fourteen minutes when, owing to the failure of the circulating-pump, the donkey pump was in use during the trial, it was made to exhaust into the condenser. The surface condenser, Plates 20 and 21, contains 6,540 square feet of tube surface, in 6,026 brass tubes of 0.79 inch external diameter and 5 feet 3 inches length between tube-plates. There are four tube-plates T, the tubes being arranged in

* With an estimated mean effective pressure of 50 lbs. per square inch in the cylinder, and at 240 revolutions per minute, which was its mean speed throughout the trial, the circulating-pump engine would develop about 47 indicated horse-power.

“ Ville de Douvres.”

two sets ; and the circulating water, entering at W, is divided between them by means of deflecting plates P. In this way the circulating water is made to pass three times through the condenser, entering at the top so that the coldest water meets the hottest steam. There is no feed-heater. The base of the condenser is 13 inches above the foot-valve of the air-pump, Plate 20, and 3·15 inches above the upper surface of the air-pump piston when at the bottom of its stroke. The bottom edge of the aperture by which the water escapes from the hot-well is 17·7 inches above the upper surface of the air-pump piston when at the top of its stroke.

Paddle-wheels.—The two paddle-wheels are fitted with curved feathering floats of steel. Their diameters are 22 feet 10 inches over the floats, and 14 feet 2 inches inside the floats, so that their mean diameter is 18 feet 6 inches. In each wheel there are nine floats, each 10 feet broad and 4 feet 4 inches deep, pivoted round a circle of 19 feet 2 inches diameter. When the vessel has a mean draft of 9 feet $0\frac{3}{4}$ inch, which was her mean draft during the trial, the maximum immersion of the inner edges of the submerged floats is about 17 inches, or one-third of the depth of the floats.

Boilers.—Steam is supplied by four single-ended boilers, Plate 18, designed for a working pressure of about 118 lbs. per square inch above the atmosphere. The furnaces, combustion chambers, tube-plates, and lower portions of the fronts of the boilers are of iron, and the remainder is of Siemens-Martin steel. The boilers are 13 feet mean diameter and 10 feet long, with three plain furnaces in each, or twelve furnaces in all. The total grate area is 236 square feet, each grate being 6 feet $6\frac{3}{4}$ inches long and 3 feet broad. There are 66 wrought-iron fire-bars of the ordinary type in each fire, arranged in three sets of 22 each. The total heating surface in the four boilers is 7,340 square feet, of which 6,280 square feet is tube surface. The total heating surface is therefore 31·1 times, and the tube surface 26·6 times the grate area. There are in all 1,356 tubes, of which 312 are stay-tubes. The tubes are all 2·48 inches external diameter and 7 feet $1\frac{5}{8}$ inch long between plates, their length being

“ Ville de Douvres.”

therefore 34·5 times their external diameter. The internal diameter of the ordinary tubes is 2·24 inches, and of the stay-tubes 1·93 inch. There are two funnels, one for each stoke-hold; their internal diameter is 5 feet 3 inches, and the total height of each is 49 feet 8 inches above the centre of the lowest furnaces. The total cross-sectional area through the tubes is 35·0 square feet, and the total area across the two funnels is 43·3 square feet. The volume of the boilers, including the space between each pair, is 6,210 cubic feet.

The boilers are worked under forced draught on the closed stoke-hold system. The two stoke-holds are situated one forward and one aft of the engine-room, and communicate with it by air-locks. On the stoke-hold side of each of the two bulkheads which separate the stoke-holds from the engine-room is placed a centrifugal fan F, Plate 19, 60 inches diameter and $20\frac{1}{4}$ inches wide, driven direct by a three-cylinder Brotherhood engine in the engine-room; these maintain an air-pressure equivalent to from 0·7 to 1·0 inch of water in the stoke-holds. The two fan engines have each three cylinders, 5 inches diameter, and 5 inches stroke.* They are supplied with steam from the main boilers and can be exhausted into the atmosphere, the receiver, or the condenser; during the trial they both exhausted into the atmosphere. The effect of this arrangement of forced draught with the block fuel used during the trial was in this case to fill the whole atmosphere in the stoke-hold with a fine dust, the blocks being broken up with hammers instead of being cut with hatchets.

Weights.—The total weight of the engines and boilers and all mountings, including water in condenser, pipes, and boilers, is about 361 tons, exclusive of the two paddle-wheels. The following are the weights of the various parts of the machinery, boilers, and accessories, as given by the makers :—

* Mr. Brotherhood states that each of these fan engines would develop about 14 indicated horse-power at a speed of 404 revolutions per minute, which was the mean speed during the trial. The corresponding mean effective pressure in the cylinders would be about 47 lbs. per square inch.

“ Ville de Douvres.”

	Tons.
Main engines alone.	145·27
Paddle-wheels	45·21
Circulating pump	2·20
Donkey pump	1·74
Pipes, valves, &c.	10·37
Water in condenser, pipes, and pumps	7·85
Boilers, &c.	132·35
Water in boilers	61·51
Total	<u>406·50</u>

Duration of Trial.—The duration of the trial from start to finish was exactly 9 hours, or 540 minutes.

Fuel Measurement.—Block fuel was used throughout the trial. It had been hoped that the total quantity of fuel used might be arrived at by counting the blocks and weighing only a portion of them; but they were found to vary so much in size and weight that this was impossible, and the whole of the fuel used throughout the trial was weighed in baskets by means of spring balances in the stoke-holds, as in the former trials (Proceedings 1889, page 237; 1890, pages 205, 214, 226; and 1891, page 204). About 150 lbs. at a time was put down on the floor beside each boiler. The trial was started with clean floors, and as far as possible the time of first stoking from each weighed lot of fuel was noted, as well as the time when the whole of the weighed fuel was finished. Owing to the rapidity with which the firing had occasionally to be carried on, it was not always found possible to note these times, the whole attention of the observers being sometimes devoted to the weighing and registering of the quantity of fuel used, and to seeing that no unweighed fuel was thrown on the fires. Therefore although the total quantity of fuel used during the trial, as well as the quantity used by each of the four boilers, may be taken as correct within the ordinary limits of error, the intermediate points on the line of fuel consumption cannot be vouched for to the same degree of accuracy.

The fires were cleaned once during the trial, and the clinker and ashes were measured after the trial was over, the total amount being

"Ville de Douvres."

2,367 lbs. in the forward stoke-hold, and 2,393 lbs. in the after stoke-hold, or a total of 4,760 lbs. in all, which is about 7·2 per cent. of the whole fuel used.

The block fuel used throughout the trial was from the manufactories of M. Dehaynin of Marcinelle, and M. Henin of Chatelineau. Samples were taken from the weighed lots of fuel frequently during the trial; and after a thorough mixture of all these samples, the final analyses, which have again been kindly made by Mr. C. J. Wilson, are as follows:—

	Fuel as used.	Dry Fuel.
Carbon	84·65 per cent.	86·74 per cent.
Hydrogen.	3·98 " "	4·08 " "
Moisture	2·41 " "	0·00 " "
Ash.	5·30 " "	5·43 " "
Nitrogen, Sulphur, Oxygen, &c., by difference	3·66 " "	3·75 " "
	<u>100·00</u>	<u>100·00</u>

A sample of the ashes was also collected, and has been analysed by Mr. Wilson as follows:—

Loss on ignition (= Carbon)	42·86 per cent.
Mineral matter	57·14 " "
	<u>100·00</u>

The calculated calorific value of the fuel is 14,390 thermal* units per lb., which corresponds with the evaporation of 14·90 lbs. of water from and at 212° Fahr., and to an equivalent carbon-value of 0·99 lb. per lb. of fuel. The total fuel used was as follows:—

After stoke-hold, port side	15,583 lbs.
" " starboard side	16,742 lbs.
Forward " port side	16,737 lbs.
" " starboard side	17,358 lbs.
	<u>66,420 lbs.</u>

This amounts to 7,380 lbs. per hour, or 123 lbs. per minute.

* For values of constants, see Proceedings 1891, page 287.

“Ville de Douvres.”

Furnace Gases.—Eighteen samples of the furnace gases were obtained, a sample from each funnel being collected over mercury by Mr. Wilson each hour as the trial went on. The analyses of these samples are given in Table 13, pages 144 and 145, the samples collected from each funnel being grouped together and their mean analyses given separately, as was done in the case of the s.s. “Colchester” (Proceedings 1890, Table 4, pages 216 and 217), which also was provided with a pair of funnels. The mean analyses for both funnels are also given; and these have been used in calculating the heat account, and the quantity of air required for combustion. In the present instance the volumetric analysis of each sample was not determined separately, but in several cases three or four samples from the same funnel were mixed together in equal volumes, and the analysis of each of these mixtures was determined, as indicated in Table 13. Allowance has been made for this in calculating the mean analyses for each funnel, and for both.

Two mercury thermometers of the same description as those used in former trials (Proceedings 1890, page 218) were employed to read the temperatures of the gases in the two chimneys. Both of these thermometers read up to 860° Fahr.; but unfortunately it was found that in every case, with the exception of four, the temperature considerably exceeded the maximum possible reading of the thermometer. The mean temperature in the two chimneys is therefore unknown; but from observations made of the motion of the mercury as it approached the end of the thermometer tube, it has been thought proper for the purpose of working out the heat account to assume that an excess of 50° Fahr. above the maximum possible reading of the thermometer may be taken as representing this temperature within reasonable limits of accuracy. For the purposes of the calculations which follow, 910° Fahr. is therefore assumed to be the mean temperature of the chimney gases. The mean air temperature on deck was 64° Fahr.

The mean vacuum in the chimneys was measured by a U gauge in each funnel, each of which gave a mean reading of 0.22 inch of water. The mean chimney-draught during the trial corresponded

TABLE 13 (continued on opposite page).

VILLE DE DOUVRES TRIAL.

Analyses of Funnel Gases by Volume.

	No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.
		Per cent.	Per cent.	Per cent.	Per cent.
FORWARD FUNNEL.	2	9.99	0.00	9.52	80.49
	4	10.19	0.00	9.22	80.59
	6	12.66	0.00	6.69	80.65
	8				
	10				
	12	9.78	0.00	9.92	80.30
	14				
	16				
	18				
	Mean	10.81	0.00	8.72	80.47
AFTER FUNNEL.	1	12.61	0.00	6.58	80.81
	3	14.06	0.00	5.23	80.71
	5	12.21	0.00	7.32	80.47
	7				
	9				
	11	11.84	0.00	7.72	80.44
	13				
	15				
	17				
	Mean	12.30	0.00	7.18	80.52
Mean of Both Funnels		11.55	0.00	7.95	80.50

* Mixed in equal volumes,

(continued from opposite page) TABLE 13.

VILLE DE DOUVRES TRIAL.

Analyses of Funnel Gases by Weight.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Time of Collecting.
	Per cent.	Per cent.	Per cent.	Per cent.	
2	14.66	0.00	10.16	75.18	10.45 a.m.
4	14.95	0.00	9.83	75.22	11.45 "
6	18.39	0.00	7.07	74.54	12.45 p.m.
8					1.45 "
10					2.45 "
12					3.45 "
14					4.45 "
16	14.36	0.00	10.60	75.04	5.45 "
18					6.45 "
Mean	15.80	0.00	9.29	74.91	
1	18.32	0.00	6.95	74.73	10.15 a.m.
3	20.31	0.00	5.49	74.20	11.15 "
5	17.76	0.00	7.74	74.50	12.10 p.m.
7					1.20 "
9					2.15 "
11	17.25	0.00	8.18	74.57	3.15 "
13					4.15 "
15					5.15 "
17					6.15 "
Mean	17.88	0.00	7.60	74.52	
Mean of Both Funnels	16.84	0.00	8.44	74.72	

and the mean analysis taken.*

“ Ville de Douvres.”

therefore with a pressure of from 0·92 to 1·22 inch of water (page 140).

Feed-Water Measurement.—Owing to the large quantity of water required by the engines (over 1,100 lbs. per minute), it was found impracticable to measure the feed in tanks as in former trials; and it was ultimately decided to employ water-meters for this purpose. The arrangement of the meters and their connections during the trial is shown in Plate 11. The meters used were two 4-inch Kennedy's positive piston water-meters, kindly lent to the Committee by the makers, the Kennedy's Water-Meter Co., Kilmarnock, by whom they were specially constructed for use on this trial. The Committee are greatly indebted to the Company and to their managing director, Mr. Thomas Kennedy, for the generous way in which they volunteered to provide the meters and their fittings for use on the trial. The two meters, each of which was capable of measuring 32,000 gallons per hour, were placed between the feed-pumps and the boilers, and were arranged in parallel circuit on a two-branch pipe fitted with stop-cocks, as shown in Figs. 1 and 3, so that the whole of the feed-water could be made to pass through either of the meters or could be divided between the two. Only one of the meters however was in use during the trial, as it was found to do its work admirably and to require very little care or attention on the part of the observers. The meters were tested at Kilmarnock before the trial under different conditions and at various speeds, and were found to give an average excess reading amounting to three-quarters of one per cent., which has been allowed for in the totals. After the trial was over, the meter which had been used to measure the feed-water was again tested, and its correction was found not to differ sensibly from that obtained during the tests made before the trial. The whole of the steam used by the main engines and all the auxiliary engines is supplied by the main boilers; so that the feed-water for all these engines passed through the meter, and is included in the totals.

The reading of the meter index was noted every quarter of an hour throughout the trial. The total amount of water used by all the engines was 595,620 lbs., during a total time of 9 hours, or

“ Ville de Douvres.”

540 minutes. This is equivalent to 66,180 lbs. per hour, or 1,103 lbs. per minute. The rate at which the feed-water was supplied and the variations of its temperature are shown in Plate 12.

Both at the beginning and at the end of the trial the boiler pressure was rising, as will be observed from the diagram, Fig. 6, Plate 13; but the water-level in the boilers averaged 2.82 inches lower at the finish than at the commencement. This corresponds with a total of 6,220 lbs. of water, or a little over one per cent. of the total feed; this amount has been included in the figures given above. It may be of interest to note that an error of one inch in reading the level of one of the boilers, which is certainly a greater error than could have occurred, would make a difference of only about 550 lbs., or less than 0.1 per cent. of the total feed-water.

The temperatures of the circulating water and of the discharge water were measured at about half-hourly intervals throughout the trial. Calculating from these observations, the mean temperature of the circulating water was 61.7° Fahr., and of the discharge water 85.0° Fahr. The ratio of condensing water to condensed steam, calculated from the respective quantities of heat taken up per lb. of condensing water, and given out per lb. of condensed steam, was 43.1 to 1.

Feed-Water to Auxiliary Engines.—Separate runs of the auxiliary engines, to determine the quantity of feed-water used by them individually, were made on 9th September, the day following the trial. Each of these runs lasted for two hours, and from the results obtained the feed-water used by the auxiliary engines throughout the trial has been computed. In each run, the speed of the auxiliary engine and the boiler pressure were maintained as far as possible the same as during the trial. No water was supplied to the boilers during the run, the water-level in the boilers being allowed to fall gradually; and at the end of two hours the engine was stopped, and a sufficient quantity of water pumped through the meter into the boilers to raise the water-level in them just to the position in which it stood at the commencement of the run. This measured quantity

“Ville de Douvres.”

of water has been taken to represent with sufficient accuracy the consumption of the engine during its two hours' run.

The water used by one of the two three-cylinder Brotherhood engines driving the fans was found to be 2,120 lbs. in the two hours' run, at a mean speed of 376 revolutions per minute. Correcting for the mean speed of these engines during the trial, namely 404 revolutions per minute, this is equivalent to 1,140 lbs. per hour for each fan engine, or 20,520 lbs. for both during the nine hours' trial.

The circulating-pump engine consumed 4,140 lbs. of feed-water at a mean speed of 240 revolutions per minute, which was also the mean speed during the trial. This is equivalent to 2,070 lbs. per hour, or 18,630 lbs. during the nine hours' trial.

On the assumption that these figures hold good for the nine hours' trial, the total feed-water used by the three auxiliary engines during the trial was 39,150 lbs., which is 6·57 per cent. of the whole feed-water consumed. The following table shows the relative consumptions of feed-water by the main engines and by the three auxiliary engines on this assumption.

Feed-Water consumption.	Total.	By Main engines.	By Auxiliary engines.
	Lbs.	Lbs.	Lbs.
Throughout trial (9 hours). .	595,620	556,470	39,150
Per hour	66,180	61,830	4,350
Per minute	1,103	1,030·5	72·5
Per revolution of main shaft .	29·96	27·99	1·97

It was found impossible to arrange for the separate measurement of the supplementary feed-water. All that was used passed through the meter, and is included in the totals given above.

Priming-Water Tests.—Three times, at about equal intervals during the trial, samples of the boiler water were taken, and at the

"Ville de Douvres."

same times quantities of steam from the main steam-pipe were collected and condensed. These samples were afterwards analysed by Mr. Wilson to determine the quantity of salt present in each, and gave the following results:—

Sample.	Salt present.
No. 1 from boilers	88·8 grains per gallon.
No. 2 " "	115·3 " " "
No. 3 " "	113·0 " " "
No. 1 from steam-pipe	{ Each contained less than 0·16 grain of salt per gallon.
No. 2 " "	
No. 3 " "	

These analyses show that in every one of the three cases, the condensed steam contained considerably less than one-fifth of one per cent. of the boiler water, or that there was practically no priming during the trial.

The method of employing this test for the purpose of ascertaining the amount of priming at any given time is as follows. A quantity of steam from the main steam-pipe is condensed in a special surface-condensing apparatus, and collected, and at the same time a sample of water is taken separately from the boilers. Both of these samples are carefully analysed to determine the quantity of salt present in each. As the whole of the salt found in the sample from the steam-pipe must have come over from the boiler in conjunction with priming water, and not with steam, a simple calculation will show how much boiler water corresponds with the quantity of salt, if any, found in the steam-pipe sample. From this it is easy to determine what percentage of the whole feed-water has passed over from the boilers in the form of water, or in other words, what percentage there is of priming. The chemical determination for salt is a very simple one, and is capable of being carried with ease to an exceptional degree of certainty.

In order to test the accuracy of the above method, Mr. Wilson took a measured quantity of each sample of boiler water, and after mixing it with a measured quantity of the corresponding sample of

“ Ville de Douvres.”

condensed water from the steam-pipe, he determined, both by analysis of the mixture and by calculation from the quantities taken, the apparent priming shown by each of the mixtures. The following table gives the results of these experiments :—

No. of Mixture.	Apparent Priming.		Difference between Analysed and Calculated percentages.
	by Analysis.	by Calculation.	
	per cent.	per cent.	
No. 1	0·92	0·85	0·07
No. 2	0·86	0·85	0·01
No. 3	1·30	1·24	0·06

These last experiments show that the actual method of testing for priming water may be taken as giving results correct to within eight per cent. of the real amount of priming, although the latter did not itself exceed 1·3 per cent. It will be observed that in every one of the three cases, actual analysis gave a somewhat higher result than that calculated from the quantities in the mixture.

A considerable amount of water came through the indicator cocks on both cylinders, during the trial. This fact, taken in conjunction with the results of the priming tests given above, shows that water appearing at the indicator cocks, even although in considerable quantities, is no criterion as to priming.

Power Measurements.—Indicator diagrams were taken at half-hourly intervals throughout the greater part of the trial ; but towards the end the number was increased by their being taken at intervals of a quarter of an hour. In this way 21 sets of diagrams, or 84 single diagrams, were taken in all. Owing to temporary failure of two of the indicators however, a few of these diagrams were found to be imperfect and were accordingly rejected, the total number of

“Ville de Douvres.”

diagrams available for purposes of calculation being thereby reduced to 78. The indicators used were all of the Richards type, made by the Crosby Steam Gage and Valve Co., and kindly lent to the Committee by the makers for use on the trial. The high-pressure diagrams were taken with springs having a scale of 60 lbs. per inch, and the low-pressure diagrams with springs of 20 lbs. per inch. The following are the mean effective pressures in the two cylinders in lbs. per square inch :—

Cylinder.	Front.	Back.	Mean.
High-pressure . .	57·90	53·08	55·49
Low-pressure . .	15·63	15·45	15·54

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	1,444
Low-pressure cylinder	1,533
Total Indicated Horse-Power	<u>2,977</u>

The maximum indicated horse-power given by any one set of diagrams was 3,229, which occurred at 2.30 p.m., with 37·0 revolutions per minute, and boiler pressure of 108·8 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams when not slowed down was 2,757 at 6.45 p.m., with 36·6 revolutions per minute, and boiler pressure of 97·3 lbs. per square inch. In Plate 14 is given the set of diagrams nearest to the mean, which was taken at 5.45 p.m., with 37·7 revolutions per minute, and boiler pressure of 100·8 lbs. per square inch. From the 78 diagrams which were taken during the trial a mean diagram has been plotted for each of the two cylinders, and these are given in Plate 15. The continuous variations of boiler pressure are shown in Fig. 6, Plate 13; of cylinder mean effective pressures in Fig. 8; of horse-power in Fig. 5; and of speed in Fig. 7.

“ Ville de Douvres.”

If to the total indicated horse-power of the main engines, given above, were added the estimated indicated horse-powers of the three auxiliary engines in use during the trial, the mean total indicated horse-power of the main engines and the three auxiliary engines during the trial would be roughly about 3,050.

Speed.—The counter was read every half hour throughout the greater part of the trial, and every quarter of an hour towards the end, alternately with the times for taking indicator diagrams. The total number of revolutions made was 19,885 in 9 hours, giving an average speed of 36·82 revolutions per minute throughout the trial. The maximum number of revolutions per minute for any half-hour during the trial was 38·1; and the minimum, except during the time when slowed down, was 36·4 revolutions. The mean speed for the fourteen minutes from 1.10 to 1.24 p.m., when the engines slowed down owing to failure of the vacuum, was 20·2 revolutions per minute. The continuous increase of total revolutions from the beginning of the trial is shown in Plate 12.

Pressures.—As in the “ Iona ” trial, a standard gauge was used to check the pressure gauges, and a correction was made where necessary. The mean barometric pressure during the trial was 30·21 inches of mercury, or 14·84 lbs. per square inch. The mean boiler pressure was 105·8 lbs. per square inch above the atmosphere, averaged from the four pressure gauges on the boilers. The mean pressures in the high-pressure valve-chest and the intermediate receiver were respectively 99·4 and 12·0 lbs. per square inch above the atmosphere. The mean vacuum in the condenser was 20·6 inches of mercury by gauge, which corresponds with a mean absolute back-pressure in the condenser of 4·72 lbs. per square inch. The mean initial pressure in the high-pressure cylinder, as measured from the diagrams, was 93·2 lbs. per square inch above the atmosphere; and the mean pressure during admission, obtained in the same way, was 89·2 lbs. per square inch above the atmosphere. The mean vacuum in the low-pressure cylinder, as measured from the diagrams, was 8·78 lbs. per square inch below the atmosphere,

“Ville de Douvres.”

which corresponds with a mean absolute back-pressure of 6.06 lbs. per square inch in the cylinder. The poor vacuum thus indicated was the subject of considerable discussion before the commencement of the trial; and it was then understood that this was the vacuum commonly obtained when the engines were working at full power.

Boiler Efficiencies.—The mean rate of combustion in the furnaces was 31.3 lbs. of fuel per square foot of grate area per hour, or 1.01 lb. per square foot of total heating surface per hour. The total amount of feed-water pumped into the boilers was at the rate of 8.97 lbs. per lb. of fuel. The average temperature of the feed-water throughout the trial was 158° Fahr., and the temperature corresponding with the mean boiler-pressure was 342° Fahr., so that each lb. of steam must have taken up 1,060 thermal units. The equivalent evaporation from and at 212° Fahr. was therefore 9.84 lbs. of water per lb. of fuel, or 9.94 lbs. per lb. of carbon-value in the fuel. The equivalent amount of heat utilised per lb. of fuel was 9,509 thermal units, or 66.1 per cent. of the whole thermal value of the fuel. This percentage therefore represents the actual boiler efficiency.

The total calculated calorific value of the fuel burnt per minute was 1,770,000 thermal units.

The weight of dry air per lb. of fuel, calculated from the series of analyses of chimney gases given in Table 13, page 145, works out to 17.9 lbs.; so that the total weight of furnace gases per lb. of fuel would be about 18.8 lbs. Assuming the estimate of the mean chimney temperature to be correct, as given in a former paragraph, page 143, these gases were raised in temperature from 64° Fahr., the temperature of the outer air, to 910° Fahr., the estimated mean chimney temperature. Taking the mean specific heat of the gases as 0.243, this corresponds with a loss of 3,853 thermal units per lb. of fuel, or 26.8 per cent. of the whole thermal value of the fuel. In estimating the weight and specific heat of the chimney gases, it has been assumed that the whole of the hydrogen in the fuel was burnt. This assumption may not be absolutely correct, but the

“Ville de Douvres.”

error due to it is exceedingly small. The loss due to the evaporation of the moisture in the fuel was so small that it may be neglected ; and none of the eighteen gas samples collected during the trial was found on analysis to contain carbonic oxide. The two percentages mentioned above, 66.1 and 26.8, add up to 92.9 per cent., so that the quantity of heat unaccounted for was 7.1 per cent. of the whole thermal value of the fuel. This is mainly covered by radiation, but would also include any losses due to unburnt carbon passing up the chimney, imperfect combustion of the hydro-carbons, and other causes.

The weight of air theoretically necessary for the combustion of 1 lb. of the fuel is 11.1 lbs. The air actually used, 17.9 lbs. per lb. of fuel, is therefore about 1.6 times the amount theoretically required.

The weight of water evaporated from and at 212° Fahr. per square foot of total heating surface was 9.90 lbs. per hour.

The average rate of transmission of heat through the material of the boiler was 9,560 thermal units per square foot of total heating surface per hour.

Fuel Consumption.—The total fuel burnt was equivalent to 7,380 lbs. per hour. This would amount to a gross consumption of 2.48 lbs. of total fuel per indicated horse-power of the main engines per hour ; but assuming that 6.57 per cent. of the total amount was consumed in making steam for the three auxiliary engines, as already explained (page 148), this would reduce the net consumption of fuel on behalf of the main engines alone to 6,900 lbs. per hour, or 2.32 lbs. per indicated horse-power per hour, which is equivalent to 2.30 lbs. of carbon-value per indicated horse-power per hour.

Engine Efficiencies.—The total indicated horse-power of the main engines was 2,977 ; and the total gross feed-water used per hour by the main engines and the three auxiliary engines which were at work throughout the trial was 66,180 lbs. This would amount to 22.23 lbs. of gross feed-water per indicated horse-power of the main engines per hour ; but, as was shown in an earlier paragraph (page 148), 6.57 per cent. or 4,350 lbs. per hour of the total feed-

“Ville de Douvres.”

water was probably used by the three auxiliary engines: so that the net feed-water used by the main engines alone would be 61,830 lbs. per hour, which is equivalent to 20·77 lbs. of net feed-water per indicated horse-power per hour. The total actual heat received by the gross feed-water per minute was 1,169,000 thermal units, which is 66·1 per cent. of the whole heat of combustion. Similarly the actual heat received by the net feed-water used by the main engines would be 93·43 per cent. of this amount, or 1,092,000 thermal units per minute. The absolute engine efficiency of the main engines alone, or ratio of the heat turned into work by them to the heat given to the net feed-water, was 11·7 per cent.

Total Efficiency.—The combined efficiency of the boilers and engines, or ratio of the heat turned into work to the total heat of combustion of the fuel, allowing for the 6·57 per cent. of the feed-water which was consumed by the three auxiliary engines, was $0·661 \times 0·117$, which is equivalent to 7·7 per cent.

Steam from Indicator Diagrams.—The following are the results of measurements made upon the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of net feed-water used by the main engines per revolution was 27·99 lbs. :—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage present in cylinder as water.
Steam present in high-pressure cylinder after cut-off, when the pressure was 81·2 lbs. per square inch above the atmosphere	Lbs. 22·57	Per cent. 80·6	Per cent. 19·4
Steam present in low-pressure cylinder near end of expansion, when the pressure was 0·8 lb. per square inch below the atmosphere	20·29	72·5	27·5

"Ville de Douvres."

Speed of Vessel.—The following extract from the ship's log has been kindly furnished by M. Lecointe :—

Time.	Observations.	Distance measured from chart.
8 September 1891.		Nautical Miles.
7.30 a.m.	Left Ostend Harbour	0
10.30 „	Passed Nord-Hinder Light-vessel . .	26
12.14 p.m.	Passed Outer-Gabbard Light-vessel. . (speed reduced for fourteen minutes)	57
2.20 „	Passed Corton Light-vessel	90
4.18 „	Repassed Outer-Gabbard Light-vessel .	125
6. 4 „	Repassed Nord-Hinder Light-vessel .	156
7.37 „	Returned to Ostend Harbour	182

The mean speed between the times of passing Nord-Hinder light-vessel on the outward journey and arriving in Ostend Harbour, which includes nearly the whole of the trial, was therefore 17·1 knots. The mean speed over the trial, excluding the passage from Outer-Gabbard light-vessel to Corton light-vessel, during which the fourteen minutes of slowing down occurred, was 17·5 knots.

There is added to this report Table 14, pages 158-163, showing the leading results of the trial of the "Ville de Douvres," and beside these are placed the corresponding figures for the six trials which have been reported on previously, namely those of the "Meteor," "Fusi Yama," "Colchester," "Tartar," "Iona," and the subsequent trial of the "Iona" carried out by the Chief Engineer of the vessel. There is also added an appendix giving a list of the Members of this Institution and others who took part in the trial of the "Ville de Douvres."

APPENDIX.

Staff of Observers.

* Members of the Institution are marked with an asterisk.

One watch was taken by Mr. H. R. J. Burstall,* along with Mr. Bryan Donkin, Jun.,* Professor T. Hudson Beare, and Messrs. A. G. Ashcroft, W. Defries,* P. T. J. Estler, H. F. Friedrichs, L. A. Legros,* and H. A. Page. The other watch was taken by Professor Kennedy,* along with Professor D. S. Capper,* and Messrs. H. F. W. Burstall, J. T. Ewen, S. B. B. Hebb, C. E. Stromeyer, A. G. Way, R. C. B. Willis, and R. H. Willis. Mr. C. J. Wilson collected the gas samples throughout the whole of the trial. M. Kraft, Ingénieur-en-chef, M. Ortmans, and M. Nolet, of the Société Cockerill, and Professor Boulvin, of Ghent University, were on board the vessel during the trial, and the Committee are greatly indebted to them, as well as to M. Lecointe, Ingénieur de première classe, and to M. Pierrard, Ingénieur de troisième classe, of the Belgian Service du Génie Maritime, and to M. Davin, Mécanicien-chef of the "Ville de Douvres," and his staff, for the valuable assistance they rendered towards the successful carrying out of the trial. The Committee have also to express their thanks to M. le Commandant Romyn, of the "Ville de Douvres," and his officers, for their kindness and courtesies throughout the whole of the operations.

The thanks of the Committee are also due to the Chairman and Directors of the London Chatham and Dover Railway, for their kindness in providing the whole of the staff of observers with free passes from London to Dover and back, for the purpose of conducting the trial; and to M. Allo, Directeur Général de la Marine, for kindly arranging, on behalf of the Belgian Government, for the free conveyance of the staff between Dover and Ostend.

TABLE 14 (continued to page 163).

*Comparative Results of the Trials of Five Screw-Steamers,
and One Paddle-Steamer,*

1	Name of Vessel	Meteor.	Fusi Yama.
2	Date of Trial	1888 24 June	1888 14 & 15 Nov.
3	Duration of Trial hours	17·15	13·95
4	Type of Engines	Triple	Compound
5	Cylinder diameter, high-pressure inches	J 29·37	N 27·35
6	" " intermediate inches	J 44·03	...
7	" " low-pressure inches	J 70·12	N 50·3
8	Stroke, length inches	47·94	33
9	Boilers, number of main boilers	2	1
10	" " single-ended or double-ended	double	single
11	Furnaces, total number	12	3
12	Heating surface, total square feet	6,648	2,257
13	" " tubes square feet	5,760	1,689
14	Grate area square feet	208	52
15	Total heating surface to grate area ratio	32·0	43·4
16	Tube surface to grate area ratio	27·7	32·5
17	Grate area to flue area through tubes ratio	—	4·0
18	" " to area through funnel ratio	5·0	3·2
Mean Pressures.		Lbs. per square inch.	
19	Mean boiler-pressure above atmosphere	145·2	56·84
20	" " admission " high-pressure cylinder above atm.	134·4	50·3
21	" " effective " high-pressure cylinder	58·46	30·74
22	" " " intermediate " "	19·50	...
23	" " " low-pressure " "	12·38	10·87
24	" " " total reduced to low-pressure cyl.	29·9	19·9
25	" " exhaust " low-pressure cylinder below atm.	11·6	10·9
26	" " vacuum in condenser below atm.	12·17	12·48
26A	" " back-pressure in condenser, absolute	2·73	2·32

J = Jacketed. N = Not jacketed.

(continued on next page) TABLE 14.

S.S. "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR," "IONA";
P.S. "VILLE DE DOUVRES."

Colchester.	Tartar.	Iona. (Committee.)	Iona. (Chief Eng.)	Ville de Douvres.	1
1889 9 Nov. 10·88 { Twin Compound }	1889 27 Nov. 10·08 Triple	1890 13 & 14 July 16 Triple	1890 15 August 10·88 Triple	1891 8 September 9 { Compound Inclined }	2 3 4
(two) N 30 ... (two) N 57 36	N 26·03 J 42·03 J 68·95 42	J 21·88 N 34·02 N 56·95 39	J 21·88 N 34·02 N 56·95 39	N 50·12 ... N 97·12 72	5 6 7 8
2 double 12 5,820 4,770 220	2 double 8 5,226 4,366 161	2 single 4 3,160 2,590 42	2 single 4 3,160 2,590 42	4 single 12 7,340 6,280 236	9 10 11 12 13 14
26·5 21·7 5·5 4·8	32·5 27·1 4·5 4·2	75·2 61·7 2·3 1·4	75·2 61·7 2·3 1·4	31·1 26·6 6·7 5·5	15 16 17 18
Lbs. per square inch.					
80·5	143·6	165·0	162·0	105·8	19
{ 64·3 59·4 }	121·4	142·5	147·8	89·2	20
{ 45·65 42·07 }	36·89	46·65	47·33	55·49	21
... { 13·42 12·42 }	20·07 7·18	20·44 7·16	20·21 7·96	... 15·54	22 23
24·8	19·8	21·13	21·95	30·17	24
{ 10·6 10·5 }	10·5	12·74	12·8	8·78	25
12·49	12·9	13·88	13·76	10·12	26
2·51	1·70	0·70	1·04	4·72	26A

J = Jacketed. N = Not jacketed.

TABLE 14 (*continued from preceding page*).

*Comparative Results of the Trials of Five Screw-Steamers,
and One Paddle-Steamer,*

	Name of Vessel	Meteor.	Fusi Yama.
27	Revolutions per minute, mean . . . revs.	71·78	55·59
28	Piston Constant, high-pressure cyl. . H.P.	11·31	5·36
29	„ „ intermediate „ . H.P.	26·00	...
30	„ „ low-pressure „ . H.P.	66·65	18·32
31	Indicated horse-power, high-p. „ I.H.P.	662	168·2
32	„ „ inter. „ I.H.P.	507	...
33	„ „ low-p. „ I.H.P.	825	203·1
34	„ „ mean total I.H.P.	1,994	371·3
35	Fuel burnt per minute . . . lbs.	66·75	16·45
36	„ „ per hour . . . lbs.	4,005	987
37	„ „ per square foot of . . .		
	grate area per hour lbs.	19·25	18·98
38	„ „ per square foot of total		
	heating surface per hour lbs.	0·602	0·437
39	„ „ per indicated		
	horse-power per hour lbs.	2·01	2·66
40	Carbon-value of 1 lb. of fuel as used . lbs.	0·878	0·878
41	„ „ equivalent per indicated		
	horse-power per hour lbs.	1·76	2·33
42	Feed-water per minute . . . lbs.	497·7	131
43	„ „ per hour . . . lbs.	29,860	7,860
44	„ „ per square foot of total		
	heating surface per hour lbs.	4·49	3·48
45	„ „ per lb. of fuel . . . lbs.	7·46	7·96
46	„ „ per lb. of fuel		
	from and at 212° F. lbs.	8·21	8·87
47	„ „ per lb. of carbon-value		
	from and at 212° F. lbs.	9·62	10·10
48	„ „ per indicated		
	horse-power per hour lbs.	14·98	21·17

(continued on next page) TABLE 14.

S.S. "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR," "IONA";
P.S. "VILLE DE DOUVRES."

Colchester.	Tartar.	Iona. (Committee.)	Iona. (Chief Eng.)	Ville d ^e Douvres.	
{ 86·0 }	70·0	61·1	63·9	36·82	27
{ 87·1 }					
{ 10·71 }	7·73	4·41	4·61	25·99	28
{ 10·84 }					
{ ... }	20·42	10·82	11·32	...	29
{ 39·55 }	55·27	30·54	31·93	98·56	30
{ 40·06 }					
{ 490·3 }	283·7	205·6	221·0	1,444	31
{ 457·9 }					
{ ... }	408·5	221·2	231·7	...	32
{ 532·2 }	395·2	218·6	255·0	1,533	33
{ 499·3 }					
{ 1,022·5 }	1,087·4	645·4	707·7	2,977	34
{ 957·2 }					
95·7	32·0	15·7	16·3	123	35
5,742	1,920	942	978	7,380	36
26·1	11·93	22·4	23·3	31·3	37
0·987	0·367	0·298	0·310	1·01	38
2·90	1·77	1·46	1·38	{ 2·48 }	39
0·913	1·031	1·02	—	{ 2·32* }	40
2·65	1·82	1·49	—	{ 0·99 }	41
				{ 2·46 }	
				{ 2·30* }	
717	359·4	143·6	—	1,103	42
43,020	21,564	8,616	—	66,180	43
7·39	4·13	2·73	—	9·02	44
7·49	[11·23]†	9·15	—	8·97	45
8·53	[13·06]†	10·63	—	9·84	46
9·34	[12·67]†	10·42	—	9·94	47
21·73	[19·83]†	13·35	—	{ 22·23 }	48
				{ 20·77* }	

* Allowing for the three auxiliary engines, as on pages 154 and 155.

† Proceedings 1890, page 233.

TABLE 14 (continued from preceding page).

*Comparative Results of the Trials of Five Screw-Steamers,
and One Paddle-Steamer,*

	Name of Vessel	Meteor.	Fusi Yama.
49	Calorific value of 1 lb. of fuel as used Th. U.	12,770	12,760
50	Percentage of line 49 taken up by		
51	" " " " feed-water per cent.	62.0	67.2
52	" " " " carried away by		
52	furnace gases p. cent.	21.9	23.5
52	" " " " lost by imperfect		
53	combustion per cent.	3.6	0.0
53	" " " " used in evaporating		
54	moisture in coal p.c.	1.2	0.9
54	" " " " unaccounted for p.c.	11.3	8.4
55	Heat taken up by feed-water per min. Th. U.	528,600	141,100
56	" turned into work per minute Th. U.	85,240	15,870
57	" taken up by feed-water per indicated horse-power per minute Th. U.	265.6	380.0
58	Efficiency of boiler (line 50) . per cent.	62.0	67.2
59	" of engine (line 56 ÷ line 55) p. c.	16.1	11.2
60	" of engine and boiler combined		
60	(line 58 × line 59) per cent.	10.0	7.6
61	Mean velocity of steam through		
61	water-surface in boilers per minute feet	—	6.28
62	Space occupied by boilers per I.H.P., cub. ft.	2.72	4.53
63	Weight of engines, boilers, &c.,		
63	with water, per I.H.P. ton	0.20	0.27
64	Clearance volume, high-p. cyl. per cent.	12.4	8.5
65	" " inter. " per cent.	9.3	...
66	" " low-p. " per cent.	8.02	5.0
67	Clearance surface, high-p. cyl. square feet	—	17.3
68	" " inter. " square feet	—	...
69	" " low-p. " square feet	—	42.5
70	Speed of vessel, mean, during trial knots	14.6	—
71	Mean temperature of outer air. . Fahr.	—	55°
72	" " " chimney gases. Fahr.	791°	578°
73	" " " feed-water . Fahr.	163°	129.5°
74	" " " boiler steam . Fahr.	363°	304°
75	" " " circulating water Fahr.	—	—
76	" " " discharge water Fahr.	—	—
77	" " " condensed steam Fahr.	138°	132°
78	Condensing surface, total square feet	3,200	—
79	Condensing surface ÷ feed-water per minute	6.43	—
80	Condensing water to condensed steam ratio	—	—

(concluded from page 158) TABLE 14.

S.S. "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR," "IONA";

P.S. "VILLE DE DOUVRES."

Colchester.	Tartar.	Iona. (Committee.)	Iona. (Chief Eng.)	Ville de Douvres.	
13,280	14,995	14,830	—	14,390	49
62·0	—	69·2	—	66·1	50
28·0	22·1	16·2	—	26·8	51
1·3	0·0	0·0	—	0·0	52
0·4	0·0	0·0	—	0·0	53
8·3	—	14·6	—	7·1	54
788,700	[403,600]†	161,100	—	{ 1,169,000 }	55
84,630	46,490	27,590	30,250	{ 1,092,000* }	56
398·4	[371·2]†	249·6	—	{ 127,300 }	57
				{ 392·7 }	
				{ 366·8* }	
62·0	—	69·2	—	66·1	58
10·7	[11·5]†	17·1	—	11·7*	59
6·6	9·7	11·8	—	7·7*	60
8·60	3·43	1·61	—	8·61	61
2·52	4·33	4·15	4·15	2·09	62
0·20	0·27	0·31	0·31	0·12	63
(two) 9·39	14·51	12·41	12·41	15·0	64
...	9·25	10·11	10·11	...	65
(two) 6·23	5·10	7·64	7·64	12·0	66
(two) 22·6	25·4	12·75	12·75	84·73	67
...	40·1	29·14	29·14	...	68
(two) 56·9	79·6	49·5	49·5	211·46	69
14·4	—	8·6	9·0	17·1	70
55°	55°	62°	91°	64°	71
835°	477°	452°	—	910°	72
113°	101°	106°	157°	158°	73
324°	362°	373°	371°	342°	74
—	—	55·8°	78·6°	61·7°	75
—	—	75·5°	94·4°	85·0°	76
135°	120°	90°	103°	160°	77
3,000	2,250	1,360	1,360	6,540	78
4·18	6·26	9·47	—	5·93	79
—	—	52·5	62·5	43·1	80

* † See footnotes to page 161.

Discussion.

The PRESIDENT said this report upon the trial of the "Ville de Douvres" was just an illustration of what he had ventured to say in his address as to the sort of facts which the Research Committee were bringing forward. The report contained an account of everything the observers saw; and the facts were given exactly as they were observed, for each person to draw his own deductions therefrom. The first wish of the Members he was sure would be to pass a cordial vote of thanks to Professor Kennedy, and to the observers who had been associated with him in carrying out this latest trial; and to Mr. Charles J. Wilson for the analytical work done in his laboratory. Also to the Belgian Government, and the officers of their Service du Génie Maritime: especially to Monsieur Allo, Directeur-Général de la Marine, Monsieur Delcourt, Ingénieur-en-chef, Directeur, and Monsieur Lecoite, Ingénieur de première classe, for the opportunity afforded for carrying out a trial on one of their steamers, and for all the facilities rendered by them in connection therewith. Also to the Société Cockerill and their officers: especially to Monsieur Greiner, Directeur-Général, Monsieur Kraft, Ingénieur-en-chef, and Monsieur Ortmans, Ingénieur; and to Professor Boulvin of Ghent University; for the assistance rendered by them for the successful carrying out of the trial, and for the valuable information supplied in connection with the preparation of the report. Also to Kennedy's Water Meter Co., Kilmarnock, and to their managing director, Mr. Thomas Kennedy, for specially constructing two of their 4-inch water meters for use on this trial, and for lending them to the Committee free of charge. And to the Chairman and Directors of the London Chatham and Dover Railway, for providing the whole of the staff of observers with free passes from London to Dover and back, for the purpose of conducting the trial; and to Monsieur Allo, Directeur-Général de la Marine, for arranging on behalf of the Belgian Government for the free conveyance of the staff between Dover and Ostend.

The vote of thanks was heartily passed.

The PRESIDENT wished, before the discussion commenced, to remind the meeting that the subject chiefly to be criticised was not the construction of the engines which had been experimented with. The Research Committee had been most generously allowed the use of the steamer, and had been furnished liberally with all the details of the engines; and therefore it would be a little ungenerous to criticise them in any disparaging sense. But any comment on points connected with the engines, which bore upon the results obtained, would of course be perfectly legitimate. What was wanted was criticism upon the observations made and upon the results obtained, and not upon the mechanical construction of the engines.

Sir FREDERICK BRAMWELL, Bart., Past-President, had but little to say in any event, but after the caution just received from the President that little had become still less, owing to the great difficulty of separating comments upon the results reported and remarks on the engines from which those results had been obtained. The Committee appeared to consider it right to separate the fuel and the water that were employed in driving the auxiliary engines from the consumption for the main engines. In this view he could hardly agree. The main engines could not work without circulating water for the condenser; and if the circulating water was supplied by a separate engine, as it was in this case, that separate engine was only a substitute for a circulating pump worked from the main engines themselves. Again the main engines could not work without feed-water; and if the feed-water was put in by an independent engine, the latter was only a substitute for a feed-pump attached to the main engines. Further, as regarded the fuel used in working the engines for the forced draught, this was an expedient by which the steam consumed by the now obsolete steam-jet was saved, or, looked at in another way, was an expedient by which an equally good draught could be obtained with a lower temperature of escaping gases; and therefore again it seemed to him that the fuel needed for the forced-draught engines was properly chargeable to the main engines. With respect to the temperature of the escaping gases, it struck him

(Sir Frederick Bramwell, Bart.)

however that in the present instance, notwithstanding the forced-draught, the gases did escape at a somewhat high temperature.

Mr. CHARLES COCHRANE, Past-President, wished to say how heartily he concurred in the vote of thanks to Professor Kennedy for the way in which he and his able colleagues had worked out this subject; and how continuously increasing had been the value of their work at every one of the six successive stages through which it had advanced, from the commencement with the "Meteor" right up to the present trial of the "Ville de Douvres." Much valuable information was in his opinion to be gathered from this latest trial, with advantage not only to the Institution, but also to the Belgian Government, who he was sure would be pleased to have candid criticisms on any fault which might be found out through the medium of the trial.

On the point of condensing surface, he had been puzzled to know why the "Ville de Douvres" should have given such a poor vacuum compared with the "Iona" and others, with only a slightly different ratio of condensing surface to steam condensed. On looking into the different conditions however he found that it was due mainly to the fact that the cold condensing water was introduced into the condenser at the opposite end to that at which it should be introduced; and he thought it would be a simple matter to alter that arrangement in the condenser, and so obtain higher results than those given in the report. The mean absolute back-pressure in the "Ville de Douvres" condenser was stated at 4.72 lbs. per square inch (page 152); while as a matter of course the condenser would work best if the cold water were admitted at the place where there was the least elastic force of steam, in order if possible to kill the last breath of steam by the coldest water that could be brought to bear upon it.

Another point was that between the vacuum in the low-pressure cylinder and the vacuum in the condenser there was a further considerable loss, amounting to 1.34 lb. per square inch. This seemed to point to the desirability of a larger exhaust pipe for conveying the steam from the cylinder to the condenser: which also was a matter of easy remedy if his surmise was correct.

Another highly interesting point was that, on comparing the various trials, it was found that the triple-expansion engine took the lead throughout, and in the most marked way; there was no question about the superiority of the triple throughout all these experiments. In the case of the "Iona," where there was a comparison between the Committee's trial and that of the Chief Engineer, he had been anxious to see what was the ratio of condensing water to condensed steam. In the Committee's trial of the "Iona" he found this ratio was 52.5 to 1; but in the Chief Engineer's it appeared to be 62.5 to 1, in order to obtain practically the same vacuum in the condenser. The difference arose from the simple fact that in the Mediterranean, with condensing water having an initial temperature of 78.6° and rising only 16° to 94.4° Fahr., a larger quantity had to be used, in order to maintain the same vacuum, than when the initial temperature was only 55.8°, rising 20° to 75.5°. In the "Ville de Douvres" the ratio was reduced to 43.1 to 1.

Another feature in the "Ville de Douvres" was that there was no feed-heater. In the "Iona," in the Chief Engineer's trial, the feed-water was sent into the boiler at 157° Fahr., whereas in the Committee's it was only at 106°, or about the temperature due to the pressure in the condenser. There must evidently have been some means of supplying extra live steam to the water in the Chief Engineer's trial, to have raised the temperature of the feed-water from 106° up to 157°. This he thought was probably worth notice.

Another point which had rather puzzled him was as to the waste of water that took place through the leakage of joints and so on. This he had in vain endeavoured to ascertain from the figures given in the report; and he now understood that it had not been observed in the trial of the "Ville de Douvres." It was however a matter which might well be inquired into in any further observations.

In connection with the previous report on the "Iona" trial (Proceedings 1891, page 287) he noticed that a higher calorific value had been given for hydrogen than had formerly been adopted. For the purpose of checking the results in the Tables, it was important to know what was now taken for the value of a unit of hydrogen burnt into water, as compared with what it formerly stood

(Mr. Charles Cochrane.)

at, in order to see how the thermal units had been arrived at in the report. A reference therefore to the calorific value adopted was desirable for making the calculations perfectly clear. Similarly in estimating at 11·7 per cent. (page 155) the absolute engine efficiency of the main engines alone, or the ratio of the heat turned into work by them to the heat given to the net feed-water, he should be glad if it were expressly stated that the calculation was made on the basis of Joule's equivalent, namely 772 foot-lbs. per heat unit. This would enable the calculations to be more readily followed.

M. KRAFT pointed out that the Ostend mail boats had been built under special conditions to perform a special service. Carrying as they did the English and continental mails, the first conditions they had to fulfil were high speed and safety. The entrance of the harbour at Ostend limited the draught of water to about $8\frac{3}{4}$ feet, thus giving predominance to the question of weight of the machinery. As the "Ville de Douvres" took only 3 to $3\frac{1}{4}$ hours for the passage from Ostend to Dover, consumption of fuel became so far a secondary consideration as hardly to concern the practical efficiency of the engines. The limit of weight allowed did not permit the use of highly economical engines; and forced draught was indispensable, not with the aim of economy of fuel, but for a sufficient production of steam. The contract speed required by the Belgian Government was 17·5 knots; and in the severe official trial, which was made not at a measured mile but over a much longer measured distance, a mean speed of 18·955 knots was realised, and the builders received a speed premium of £4,000. In this trial the main engines developed 4,431 indicated horse-power. As stated in the report (page 140), the total weight of the engines and boilers and all mountings, including water in condenser, pipes, and boilers, was about 361 tons, exclusive of the two paddle-wheels; and from the comparison given in line 63 of Table 14 it was seen that the weight per indicated horse-power, amounting to only 0·12 ton in the "Ville de Douvres," was less than in any of the other steamers tried, in which it ranged from 0·20 up to 0·31 ton per I.H.P. The high speed of so large a vessel, and the small weight of such powerful engines, were certainly worth noting.

As to the circulation of the water in the surface condenser, he entirely agreed with Mr. Cochrane (page 166) in the principle that every heating or cooling apparatus should be arranged with counter currents, instead of with both currents running in the same direction. But a calculation of the transmission of heat in this particular instance would show that the difference between counter current and similar current was inconsiderable. The principal reason of the indifferent vacuum did not lie there. It was due to the imperfect subdivision of the water current passing through the inside of the condenser tubes. There were corners of the water chambers in which the flow of water was not satisfactory, and in which deposits even of mussels had been found. Owing also to the predominant consideration of weight, the circulating pump was rather small for a condenser of that size. It was doubtless well to divide the current of condensing water between the two halves of the condenser, as was here done, so as to give it a better chance of penetrating everywhere; and it would perhaps be better still to have two circulating pumps, one to each half of the condenser. Why the vacuum had been so indifferent in the Committee's trial he could not say; in regular work it was much better, rising generally to $22\frac{1}{2}$ or 23 inches of mercury and even higher.

The Belgian Government had now ordered two new fast mail boats, one from Messrs. Denny of Dumbarton, and the other from the Société Cockerill. These boats would be ready to start running next year, and were intended to have a speed of $21\frac{1}{2}$ knots with about 8,000 indicated horse-power. At the proper time he should be very glad to place before the Institution the results obtained at the trials.

Professor BOULVIN considered that, as the object of the Research Committee on marine-engine trials was to collect as extensive data as possible on the behaviour and efficiency of the different kinds of marine engines now in use, they could not have done better than include among their trials one set of engines having such special features as those of a mail steamer making short runs at high speeds. The results of the present trial showed that there was room for some improvements in the condenser

(Professor Boulvin.)

of the "Ville de Douvres," and indicated clearly the nature of the improvements needed; but the defects pointed out belonged only to these particular engines themselves, and not to the class of which they were representatives. It might be of more interest to direct attention to the leading difference between the "Ville de Douvres" and the other engines tried previously, which lay in the much lighter weight of her machinery and boilers, as shown by the comparison in line 63 of Table 14. This weight, including the water in the boilers, amounted in the "Ville de Douvres" to only 0.12 ton per indicated horse-power. Taking for comparison, not the "Iona" with so much less power, but the "Meteor" with her weight of 0.20 ton per I.H.P., it would be seen that, for developing the 3,000 I.H.P. of the "Ville de Douvres," the engines of the "Meteor" would be some 240 tons heavier than those of the "Ville de Douvres." This comparison was made on the assumption that the figures given for the weights included corresponding portions of machinery; and it was to some extent to the disadvantage of the paddle-wheel engines, in which the piston speed was about 25 per cent. slower, thus rendering them so much heavier than they would otherwise have been.

If the consumption of fuel in the "Ville de Douvres," instead of being 2.46 lbs. of carbon-value per indicated horse-power per hour, had been the same as in the "Iona," or only 1.49 lbs., the saving in fuel would have been about 1 lb. per I.H.P. per hour, or 1.34 ton per hour for the 3,000 I.H.P. Assuming that the bunkers had to be filled with a supply sufficient for ten hours' steaming, corresponding with a double run in bad weather, the saving in weight of fuel would be 13 to 14 tons. As the cost of the extra fuel was of minor importance in this case, while the problem was to obtain the maximum speed with a steamer of given dimensions, the object to be aimed at was to reduce to a minimum, not the weight of fuel alone, but the sum of the weights of the fuel and the machinery. In long voyages this sum was always minimised by the more economical engines, because the weight of the fuel amounted to so large a percentage of the whole weight. This was the reason why it had been so long before compound engines had been applied to fast channel-steamers, and why low-pressure engines, some even

oscillating, had been in use as late as ten years ago for this class of steamers. The saving of 13 tons in weight of fuel would no doubt be advantageous, if it could be realised without increasing by an equal amount the weight of machinery; but in order to obtain a reduction in fuel consumption, steam-jackets would be needed on both cylinders, as well as a greater extent of boiler surface to take up more heat from the gases. It might be doubted whether there was room for these additions to the weight of machinery, within so low a margin of saving as only 13 tons in weight of fuel.

It was thus clear that engine perfection was a different thing in its relation to land engines, locomotives, war steamers, trading vessels, and mail boats; and the Research Committee had therefore taken the best course in trying marine engines of different kinds and designed for different purposes. While the construction of the vessels themselves was a matter of naval architecture, shipbuilders would none the less feel much indebted to this Institution for the valuable series of reports which had been presented by the Committee on the six trials already made. The Belgian marine department could not have done anything more advantageous to their own interests than by availing themselves of the opportunity which had been afforded them of having one of their steamers tried by the Committee; and their warmest thanks were due to the Institution for the useful information thus obtained.

Dr. ALEXANDER C. KIRK was sure the work that had been done by the Research Committee was highly appreciated by every one; and they had to thank the Chairman for the remarkable care with which he had worked out and recorded the results. The great thing done was that the performance of the boiler had here been separated from that of the engine. Ordinarily, by the help of the indicator, and by measuring the coal, sometimes more and sometimes less accurately, it was only the gross efficiency of the machine that was ascertained; but the separation of the boiler efficiency from that of the engine was a most important point. If some arrangement could be adopted whereby a record of the boiler performance could be obtained throughout a voyage, it would be a great help in maintaining the efficiency of the machinery and in judging what was the best

(Dr. Alexander C. Kirk.)

arrangement of boiler. The engine itself he thought was now known pretty thoroughly, and also what was required to make it efficient: but what was required with a view solely to efficiency was not always what was most suitable for the ultimate object aimed at. Consequently the shipowner sometimes did not think it worth while fitting his vessels with the most efficient engines; and in other cases, especially in high-speed steamers which came into port at frequent intervals after short runs, looking at the ship and engines as one whole machine, it did not pay to make the engines themselves of the highest possible efficiency. For instance the proportion of machinery in the "Iona" would be altogether unsuitable in a transatlantic steamer. Sometimes machinery was not made to work so economically as it should do, occasionally through sheer ignorance; while at other times it was quite necessary that it should be so made, in order that the ship might do its work with the utmost economy. Not only were all much indebted to the Committee for their trials, so far as these had gone, but he wished also to express the appreciation that was felt of the way in which some shipowners had put their machinery into the hands of the Committee for trial; and it would therefore be unbecoming that any criticism whatever should be made upon the greater or less relative efficiency of the different machines, except as to the cause of their efficiency or deficiency as the case might be.

MR. BRYAN DONKIN, JUN., observed that, while the water meter had been so carefully tested both before and after the trial, nothing was said in the report with regard to the indicator springs having been tested; and he should be glad to know whether they had been tested or not. In his own experience he had found they were generally wrong.

MR. H. GRAHAM HARRIS asked how the quantity of coal on the fire had been measured at the starting of the trial, both in the present and in the previous trials; and how what was left on the fire had been measured when the trial was finished. In the case of the "Ville de Douvres" there was a grate area of 236 square feet,

on which with a fire 6 inches thick there might be roughly 120 cubic feet of fuel. In some of the many experiments which he had carried out with Sir Frederick Bramwell, he had first tried to guess; as had always been done previously, the depth of the fire upon the grate; and had then raked it all out and allowed it to cool, and had afterwards weighed it. In one case, with a vertical boiler having 16 square feet of grate area, he had found that there was a difference of something like 70 per cent. in the weight of the fuel in different trials, although the thickness upon the bars was practically the same, as well as it could be measured. Neither in the present trial nor in those previously reported did the Committee appear to have entered at all into the question of the quantity of fuel upon the grate, either at the commencement or at the end of the trial. In the "Ville de Douvres" burning 7,380 lbs. of coal per hour, if the fires were 6 inches thick and there were an error of the kind he had suggested amounting to only 50 per cent., this would represent about 60 cubic feet of fuel, amounting say to 3,500 lbs., which would be equivalent to about half an hour's run of the engines. As there were twelve furnaces, it might be said that the weight of the fuel would average itself throughout the twelve, and probably it did so; but he had mentioned this point because there was nothing said upon it in the report.

The PRESIDENT did not quite agree in the reasons that had been given by Mr. Cochrane for the imperfect vacuum, because the temperature at which the condensing water was discharged from the condenser was only 85° Fahr., whereas a good vacuum could be got with water leaving at 100° and more: so that, even at the part of the condenser which ought to have been coldest, the water was cold enough to produce a good vacuum, for it was discharged in the present trial not warmer than it often was in the Red Sea, where he understood there was no difficulty in getting a good vacuum.

Mr. COCHRANE suggested that, for the further elucidation of the efficiency of the condenser, it would be desirable to add in Table 14, from the data furnished in the successive reports, the mean

(Mr. Charles Cochrane.)

temperature of the condensed steam corresponding with the observed pressure existing in the condenser, and the ratio of the condensing water to the condensed steam; also the actual area of the condensing surface, and the ratio of the condensing surface to the feed-water per minute. (See lines 26A and 77-80 accordingly added in Table 14.) When these additions were made, it would be seen that the temperature of the condensed steam at the pressure existing in the condenser of the "Ville de Douvres" was no less than 160° , which would of course militate seriously against a good vacuum, if it was really a matter of fact, as he thought must be the case.

With regard to fuel burnt per square foot of heating surface per hour, it would appear—from the comparison with the previous trials in line 38 of Table 14, and from the possibility of burning as much as 1.01 lb. of fuel per square foot of total heating surface per hour, as was done in the "Ville de Douvres," without the appearance of priming—that the "Iona" and the "Tartar," which ran on counter lines with only about one-third of that consumption, had an excessive amount of heating surface, so far as priming was concerned: that is, they need not have had so large an extent of heating surface in order to avoid priming. But this inference was immediately confronted with the counterbalancing disadvantage that, for want of larger heating surface in the "Colchester" and the "Ville de Douvres," the temperature of the chimney gases had risen to 835° in the former and 910° in the latter. Corresponding with these temperatures the heat wasted through being carried away by the chimney gases amounted to 28.0 per cent. and 26.8 per cent. respectively; while the temperature of the chimney gases in the "Iona" was only 452° , with a waste of 16.2 per cent., and in the "Tartar" it was only 477° , with a waste of 22.1 per cent. Between these two extremes there might of course be some intermediate proportion of heating surface which would secure the most economical results with a fair recovery of heat from the chimney gases.

With a view to arriving at a clearer appreciation of the conditions affecting the efficiency of condensation in the several trials already made, he had collected in Table 15 the principal figures bearing upon this portion of the subject. In this comparison it would be

TABLE 15.—*Comparative Efficiency of Condensation.*

Name of Vessel.	Condensing Surface.		Condensing Water per lb. of Condensed Steam.	Back-Pressure in Condenser. Lbs. per sq. inch absolute.	Corresponding Temperature of Condensed Steam.
	Total.	Per lb. of Feed-Water per minute.			
	Sq. Ft.	Sq. Ft.	Lbs.	Lbs.	Fahr.
Meteor . . .	3,200	6.43	—	2.73	138°
Fusi Yama . . .	—	—	—	2.32	132°
Colchester . . .	3,000	4.18	—	2.51	135°
Tartar . . .	2,250	6.26	—	1.70	120°
Iona (Committee) .	1,360	9.47	52.5	0.70	90°
Iona (Chief Eng.) .	1,360	—	62.5	1.04	103°
Ville de Douvres .	6,540	5.93	43.1	4.72	160°

noticed how, although the "Tartar" and the "Ville de Douvres" had nearly the same ratio of condensing surface to feed-water, the vacuum was only 10.12 lbs. below atmosphere in the latter, against 12.90 lbs. in the former, or 4.72 lbs. per square inch absolute pressure in the "Ville de Douvres" against 1.70 lbs. in the "Tartar." To the reason of the poorer vacuum he had already adverted (page 166); but the explanation he had attempted was modified by what Mr. Kraft had since stated in regard to the vacuum ordinarily obtained in the "Ville de Douvres," in which the area of condensing surface per lb. of feed-water per minute was 5.93 square feet. In the "Colchester," where the corresponding area was only 4.18 square feet, it would not fail to be noticed how, with this still lower ratio of condensing surface to feed-water, the excellent vacuum was nevertheless obtained of 12.49 lbs. below atmosphere, or 2.51 lbs. absolute pressure. The highest vacuums obtained were in the two trials of the "Iona," namely 13.88 and 13.76 lbs. below atmosphere, or 0.70 and 1.04 lbs. absolute

(Mr. Charles Cochrane.)

respectively, but at the expense of no less than between 9 and 10 square feet of condensing surface per lb. of feed-water per minute. The question arose whether the combined economies secured in the "Iona," in low temperature of chimney gases and in high vacuum, were real economies from a pecuniary point of view.

Some explanation he hoped would be furnished with regard to the substitution made in the "Ville de Douvres" for a steam-jacket round the high-pressure cylinder, by surrounding it with the intermediate receiver into which the steam exhausted from the high-pressure cylinder before it passed into the low-pressure. It seemed to him a prominent feature in the construction of this engine that the high-pressure cylinder was encircled by a large concentric jacket, which received the steam at the lowest pressure at which it escaped from the high-pressure cylinder. In this particular case he gathered there was a difference of 80° between the temperature at which the steam was admitted into the high-pressure cylinder, and that at which it escaped from the high-pressure cylinder to go into the low-pressure cylinder at about 15 lbs. per square inch above the atmosphere, or about 30 lbs. absolute pressure. This low-pressure steam in the receiver must exercise a cooling influence on the steam in the high-pressure cylinder all through the stroke; and from the indicator diagrams there was evidence of a slight condensation taking place in the high-pressure cylinder right through the stroke, certainly after the steam was cut off, which might naturally be expected when a difference existed of 80° of temperature between the outside surface of the cylinder and the inside surface after the cut-off had taken place. He hoped that Professor Kennedy might have something to say upon this point, in regard to which it was so desirable that the truth should be realised. Already a large degree of truth had been attained on the subject generally, owing to the valuable data and calculations which had been furnished by the Research Committee; and he regarded all that had been done as a stepping stone to the establishment of fixed data, on which not marine engineers only but land engineers also might decide what was the best ratio for heating surface, boiler capacity, condensing surface, and every other element in steam engineering. Further experiments also he hoped would

be made on quadruple expansion, which was a problem certain to come forward soon for consideration.

Mr. JAMES ROWAN considered the ultimate effect of these investigations would be to produce faster and more economical steamers. With regard to the present trial, he looked upon the "Ville de Douvres" as essentially a passenger steamer; and if this was the case it might safely be assumed that speed stood first, as had been pointed out by Mr. Kraft (page 168); and if the speed of the steamer could now be materially increased in consequence of the present investigations, he was sure the Committee would feel in some measure rewarded for their labours, and the result would also be an incentive to other owners to place steamers at their disposal for trial.

With the object of increasing the speed of the "Ville de Douvres" at a trifling expense and without increasing the coal consumption, he would in the first place suggest that a considerable increase of power would be obtained, were the low-pressure slide-valve made to cut off somewhat earlier; that is to say, more work would be realised per lb. of steam passing through the engines. The effect of this earlier cut-off would be to increase the mean effective pressure in the low-pressure cylinder, and diminish it in the high-pressure cylinder; and accordingly the indicated horse-power would be increased in the low-pressure cylinder and diminished in the high-pressure, but the net result would be a gain of perhaps 5 per cent. in the total horse-power. If it would be of interest to the Committee he could have indicator diagrams taken from the engines of either of two new fast paddle-steamers—the "Neptune" and the "Mercury," which had just been completed by his firm for the Clyde passenger traffic of the Glasgow and South Western Railway—first with the eccentric rod and slide-valve spindle in line, and secondly with the links linked up. These would show the increase in power consequent upon linking up in those engines, which indicated from 1,800 to 1,900 horse-power. Objection might be taken to this suggestion in so far that, if the horse-powers taken from each cylinder were too unequal, they might produce that jumping forward motion

(Mr. James Rowan.)

which all travellers on the Clyde had experienced in the river steamers fitted with the single-cylinder diagonal engines, until recently so popular there. [See pages 196-7.]

Secondly, it was mentioned in the report that there was no feed-heating apparatus. This however could be arranged with but little trouble and small expense, and in the most complete manner possible. All that was necessary was to lead a pipe of 1 inch or $1\frac{1}{4}$ inch diameter from the receiver to a heating coil in the hot-well, with a non-return valve upon it. When the engine was at rest the atmospheric pressure kept the valve shut; and when the engine was at work, whenever the receiver pressure rose above that of the atmosphere, then this feed-heating apparatus came into action automatically. Steam was certainly taken away thereby from the low-pressure cylinder; but by the adoption of this simple apparatus about 4 to 6 per cent. less coal would be required to produce a certain indicated horse-power than without it. It was always a most important matter that hot water and not cold water should be put into a boiler; for nothing was so severe on boilers as pumping cold water into them.

From his own experience of paddle-boats and their engines, he anticipated that, if these two proposals were adopted, at least one more revolution per minute would be got, which should propel the vessel at least a quarter of a knot faster than at present. As a marine engineer he wished to express his great admiration of the manner in which these investigations had been conducted by the Research Committee.

Mr. C. E. STROMEYER, having been one of the staff of observers, said there was one point which struck him as remarkable in these trials, namely the great regularity in the efficiency of the boilers. From line 58 in Table 14 it was seen that the lowest efficiency was 62 per cent. and the highest 69·2 per cent. In trying to find out whether there might not be some unexplained reason for this, he had paid particular attention to the percentage unaccounted for (line 54) of the calorific value of the fuel as used; and this item could at once be reduced a little, by taking into account the carbon

contained in the ashes which were found in the furnaces. In the "Ville de Douvres" for example, there was 7.2 per cent. of ashes remaining after the trial (page 142), and, as far as he remembered, this was the total for twelve hours' firing, not for nine hours' only; so that the actual ashes for the nine hours' trial would be only 5.4 per cent. The mineral matter in the ashes was stated to be 57.14 per cent.; it followed that 3.08 per cent. of mineral matter remained in the stoke-hold. Moreover 42.86 per cent. of the ashes consisted of carbon (page 142), which would reduce the loss unaccounted for by 2.32 per cent. The analysis of the fuel showed 5.30 per cent. of ash; subtracting 3.08 per cent., the difference, or 2.22 per cent. of mineral matter, must therefore have been blown up the funnel, carrying carbon with it; and he had tried to find out how much carbon was lost in that way. The sample now exhibited of deck-sweepings had been sent him by Mr. Lecointe; as could be seen, it was very black and consisted chiefly of carbon, the mineral matter amounting to only about 20 per cent.; so that it might fairly be argued that, as 2.22 per cent. of mineral matter had gone up the funnel, it must have been accompanied by four times as much carbon or 8.9 per cent. The balance account of the fuel would then be as follows:—66.1 per cent. of its thermal value was taken up by the feed-water (page 153) while being converted into steam; 26.8 per cent. was wasted with the escaping gases, a rough estimate of course and not absolutely correct; 2.2 per cent. of carbon was found in the ashes in the stoke-hold; and 8.9 per cent. was blown away up the funnel. These items made altogether 104 per cent., showing that the efficiency of the fuel was greater in the boiler than in the calorimeter. Adding 3 per cent. for radiation of the boilers, or about 1 lb. of steam condensed per square foot of external boiler surface per hour, which he thought was not an excessive estimate, this would bring the total up to about 107 per cent., as against 93 per cent. in the report. Such an excess no doubt appeared amusing; but as regarded accuracy of results he could not see that there was much to choose between a deficit and a surplus. Even these results were highly satisfactory, and Professor Kennedy and

(Mr. C. E. Stromeyer.)

Mr. Wilson might be congratulated on having got so near to the true result; it meant indeed that, halving the surplus of 7 per cent., the boiler trial was correct within $3\frac{1}{2}$ per cent., and so was Mr. Wilson's calorific estimate. A study of the experiments made on the calorific value of various fuels had shown him that no great certainty could be claimed for their results; unexpected differences occurred now and then, amounting he believed to as much as 10 or 15 per cent. The present difference was therefore comparatively small. Working out the results of the "Colchester" trial, he found that the total amounted to exactly 100 per cent., without allowing for radiation. The estimate given as regarded the carbon that had been blown away he had not the least doubt erred on the excess side, and the above percentages might safely be reduced; for, besides the pieces of coal which fell on deck, there would be much mineral dust blown away altogether. In forced-draught boilers the ends of the tubes were often coated with a sort of clinker, showing that a considerable amount of pure mineral dust was blown about, though none of this could be found in the sample exhibited: so that it would be better to assume that, instead of carrying away four times its own weight of carbon, the mineral matter was perhaps associated with only an equal amount of combustible. This estimate would reduce the efficiency of the fuel from 107 per cent. to $100\cdot3$ per cent.

In connection with the priming of the boilers, great care he thought should be exercised in collecting the boiler water. While he was in the stoke-hold he had noticed that one of the samples was taken from a gauge-glass connection; and he remembered pointing out that it ought to be blown out first, because there was a possibility of steam having become condensed in the upper part of the glass, which would find its way into the measuring pot and might produce error in the result. In fact this might account for the difference that existed in the three experiments. In the first sample of boiler water he noticed that there was only 89 grains of salt per gallon (page 149); whereas in the second and third the amounts were 115 and 113 grains respectively. It was possible that the difference of 25 grains might be due to the above cause; but if it was not, and supposing for argument's sake that all the samples were taken in

the same way, it would show that during the first interval of three hours, between samples Nos. 1 and 2, the saltiness had increased by 26 grains per gallon. Now as sea water contained 1,850 grains of salt per gallon, this increase meant that supplementary feed from the sea to the extent of more than one per cent. had been added to the boilers. Without desiring to attach any importance to these exact figures, he only wished to point out how in this way the priming of a locomotive or other land boiler could be measured; it could be done, for instance, by filling a boiler with salt water, and measuring its saltiness before starting and subsequently. Unfortunately he had not yet been able to induce any locomotive superintendents to put salt into their boilers, even though, as these experiments showed, only a little was required; but he hoped that the experiment would yet be tried, as it offered a ready means of showing whether there was any priming going on in locomotive boilers or not. Mr. Wilson's valuable test for estimating slight variations in saltiness might also be utilized for determining to what extent surface-condensers leaked. Considerable trouble was often experienced at sea from the ever increasing saltiness of the boiler water; and it would be of great importance to be able to know whether it was due to a leaky condenser. All that would be necessary would be to test the saltiness of the water in the hot well or in the feed pumps, and every two grains per gallon found there would mean that one-tenth of one per cent. of salt water was being constantly added to the feed.

One other matter to which he wished to refer was the great difference in the efficiency of the engines, which ranged, as shown in line 59 of Table 14, from 10·7 up to 17·1 per cent. Part of the difference was of course due to the various steam-pressures and the various grades of expansion; but there were other discrepancies which he thought could be accounted for only by restricted steam passages, and perhaps by the valve-motions: in fact by the friction of the steam. He would therefore further suggest that the trials would be still more interesting and valuable if in each case continuous indicator diagrams were to be constructed, showing the cylinder pressures one above the other at each point in their correct

(Mr. C. E. Stromeyer.)

relative positions, as well as a diagram showing the amount of openings of the slide-valves. This would assist in explaining the frictional resistance of the steam in its passage from one cylinder to another.

Mr. P. W. WILLANS said it was a great pleasure to read a report like the present, which however was a most difficult one to criticise, because there appeared to be nothing omitted from it, and almost every suggestion that had been made in connection with the previous engine trials appeared to have been acted upon in this. There was one novelty in the present trial, which he thought it would be a good thing to see carried further, namely the introduction of water meters. It was a simple matter with almost every boiler to use a water meter; and the information which would thereby be obtained on a long voyage as to water consumption, and the relation it bore to coal consumption, would be highly valuable, as distinguished from what was obtained on a twelve hours' run under trial. It would be most valuable to have a continuous record of the water used. In his own works he had now a meter continually in use on the boiler that was employed for testing engines, and he thus kept a continuous record both of the coal burnt and of the water consumed. Until lately meters had not been so accurate that they could be absolutely depended upon; but they were now made more accurate. One of Mr. Schönheyder's meters that he was using was found to be correct within 1 per cent., which was near enough for any ordinary trials, and gave a satisfactory record.

With regard to the mode of determining the priming, it might be of interest to mention that there was another simple means of doing so, provided the priming was not excessive. A little steam was allowed to flow from the steam pipe into a small vessel attached to it, the steam being taken as far as possible of average quality. The following three observations were then made: the pressure in the steam pipe close to the vessel; and the pressure and also the temperature of the steam in the vessel. The percentage of priming water in the sample could then be calculated from the excess of the observed temperature above that of saturated steam at the reduced

pressure in the vessel. Of course in any method of sampling for priming—not only in the one he was now speaking of, but also in the method of determining the priming by salt—it was only a certain sample of steam from which the priming was determined; and that was not exactly the same thing as taking all the steam and condensing it in the calorimeter; both methods had their disadvantages. The specific heat of superheated steam was not accurately known; it was liable to an amount of doubt, which could not at present be determined, and this might affect the result to the extent of 2 or 3 per cent. of the total priming. Having lately used this method several times, he had found the priming to be under 1 per cent., a result which agreed with previous calorimetric tests that he had made under similar conditions.

With regard to the condenser in the “*Ville de Douvres*,” he thought there was no doubt Mr. Kraft was right (page 169) as to the water probably not flowing through the whole of the condenser tubes: the figures given of the trial pointed to this conclusion. There was hot feed-water, and at the same time the temperature of the discharge water was low. It looked as though the bulk of the condensing water was flowing through a certain portion only of the tubes, and that these tubes had reached the limit at which they could transmit heat. Supposing for instance that 90 per cent. of the tubes had stagnant hot water in them, while the remaining 10 per cent. had a large quantity of cold water flowing through them, the effect would be that the limit of the capacity of the majority of the tubes to transmit heat from the steam to the water would be reached, and notwithstanding a comparatively cold circulating water the condensed steam would still be hot. This appeared to be the explanation in the present case. Whether the effect of the comparatively poor vacuum was serious was another question altogether. For some time past he had been trying to find what was the best vacuum to work with under certain conditions. It seemed to vary much; and there was no doubt that an economic limit could be reached. Owing partly to the fact that the compression of steam at a very low tension must fail to fill the clearances and to warm the clearance surface at the beginning of

(Mr. P. W. Willans.)

the stroke, and owing partly to the general reduction of temperature in the cylinder when the pressure was very low, there must be a degree of vacuum which it was not worth while to exceed. Mr. Kraft had apologised for the performance of the engines in regard to economy; but it was rather curious to observe from line 59 in Table 14 that—although the steamer was built entirely for speed and there was no great amount of expansion in the cylinders, and the expansion, as pointed out by Mr. Rowan (page 177), was not so well distributed as theoretically it might be—still the performance of the engines was practically as good as that of the other two-cylinder compound engines in the “Fusi Yama” and the “Colchester”: pointing to the conclusion that expansion might often be carried too far, and that a high vacuum might not be an entire gain. In the “Ville de Douvres” the condenser appeared to have rather more than two square feet of surface per indicated horse-power; whereas with only one square foot he had frequently got a better vacuum. This showed what might be done by properly distributing the circulating water, so as to ensure its passing through every part of the condenser equally.

Lt.-Colonel ENGLISH asked whether the capacity of the intermediate receiver could be stated, and also the extent of its surface. [This has since been added accordingly in page 138.] It was evident from the low-pressure diagrams that it had largely affected the working of the engine.

Mr. FREDERICK EDWARDS corroborated the statement in the report (page 141) with regard to the fuel consumption, that the amount could not be arrived at either by counting the blocks or by measuring. Every portion of it he considered ought to be weighed; and he was very glad that in the present case the whole of it had been weighed. The priming test he regarded as highly instructive; and this he believed was the first trial in which there had been practically no priming. In this connection therefore it would be of great interest and use to the members if fuller particulars were supplied of the boilers, of which only the general dimensions appeared to be given:

especially the actual capacity of the steam space, and how and where the steam was taken from the boiler; and also the position and dimensions of the internal steam-pipe, if there was one. In the former trial of the "Tartar" the amount of feed-water that had been measured had been found to be more than the coal would evaporate. A portion had therefore been attributed to priming; and he thought it would be of great use if a similar test were made on the "Tartar" to see what amount of priming went on in her boilers. His impression was that it would not take long to do; the ship often came to London, and it would be useful to know how much her boilers did really prime.

With regard to what Mr. Cochrane had said (page 166) about the coldest water meeting the hottest steam in the condenser, as was the case in the "Ville de Douvres," he had had several ships arranged in that way, including one of his best and largest boats; and it gave good results. His impression was indeed that he had obtained quite as good results in that way as by the reverse method of a counter-current. He greatly regretted that owing to ill-health he had been prevented from continuing to take an active part in the more recent trials. In any future trials however he should be happy to offer the assistance of some members of his staff.

The PRESIDENT hoped that Mr. Edwards had carried out his intention (Proceedings 1889, page 290) of fitting all his vessels with permanent feed-measuring apparatus.

MR. EDWARDS said he had fitted one ship, and he hoped to have been able to have a trial with her, and that the Committee would have been able to test her; but she had not been to London, and circumstances had not led to his being able to arrange the matter otherwise. Whenever he was in a position to do so, he should be happy to inform the Committee.

MR. J. MACFARLANE GRAY considered that the present report, like all the others of the Research Committee, was a most careful and valuable one. In the discussion upon the "Iona" report he

(Mr. J. Macfarlane Gray.)

had since observed he was said to have stated (Proceedings 1891, page 260) that, if the efficiency of the "Iona" engines had been calculated on the method introduced by Mr. Willans, it would have been raised from 69·2 per cent. to about 72 per cent. What he meant to say was that the figures of the Committee's trial would have given 69·2 per cent.; and if the evaporation were taken at the same rate for the coal consumption recorded in the Chief Engineer's subsequent trial, the engine efficiency on Mr. Willans' plan would have been about 72 per cent. Another 69·2 per cent. occurred in the report; but the two numbers were not related, and the equality was wholly accidental.

The results obtained in the "Iona" and in the "Ville de Douvres" were very different; but the engines were designed for quite different conditions. The latter was a fast steamer running short voyages; the former a slow cargo steamer making long voyages. The "Ville de Douvres" had only two-thirds of the initial pressure in the "Iona"; yet the "Iona" gave only two-thirds of the mean effective pressure in the "Ville de Douvres," referring all to the low-pressure cylinder. The piston area per indicated horse-power was more than 50 per cent. greater in the "Iona" than in the "Ville de Douvres." That a high initial pressure with a low back-pressure should be more economical than low initial pressure and high back-pressure was only what would be expected. It was not for demonstrating such obvious conclusions that the reports of the Research Committee were chiefly valuable. They enabled these obvious differences to be separated from the enquiry, and the theoretical duty of the steam working within the given limits of pressure to be compared with the result actually obtained; and then the more or less occult causes to be enquired into, which might have produced a defect in efficiency. When that method was applied to the "Ville de Douvres," the margin of difference was much contracted. Taking as the limits the pressures bounding the mean indicator diagrams, not quite the same as he had taken before for the "Iona," the method he had explained in Proceedings 1889, page 449, gave the following results:—

	"Iona."	"Ville de Douvres."
Initial pressure absolute, lbs. per sq. inch	164	109
Terminal " " "	5	14
Back " " "	1 $\frac{3}{4}$	6
Pounds of steam per I.H.P. theoretically	9.36	13.84
" " " actually	13.35	20.77
Efficiency of engine per cent.	70.1	66.6
Relative efficiencies	100	95

To account for this 5 per cent. difference, the "Iona" had her high-pressure cylinder jacketed with boiler steam, whereas the high-pressure cylinder of the "Ville de Douvres" was wholly surrounded by its own exhaust steam.

With reference to the efficiency of the boiler, he had given in the discussion on Mr. Blechynden's paper last year at Liverpool (Proceedings 1891, page 355) a sort of rule of thumb for the loss of calorific effect due to the heat escaping up the funnel, which he had stated was always equal to 4 per cent. of the elevation of temperature in degrees Fahr.:—that is, 4 per cent. of the difference between the temperature of the atmosphere and the temperature of the escaping gases. In the case of the "Ville de Douvres" the temperatures reported were 64° and 910° respectively; whence the loss would be 33.84 per cent., with the result that the boiler efficiency ought to be 66.16 per cent. The efficiency reported (page 153) as the result of the trial, after a somewhat elaborate calculation, was 66.1 per cent. This result might perhaps induce some of the members, when they had no better way of guessing at the boiler efficiency, to apply the rule of thumb.

Mr. CHARLES J. WILSON, referring to the calorimetric method of measuring priming mentioned by Mr. Willans (page 182), considered an objection to that plan was that it applied only to cases in which the priming was somewhat large. The great advantage in employing the salt method was that it could always be shown thereby, in cases where there was no priming, that the priming was below a certain extremely small amount, less for instance than one-tenth of one per cent. In nearly all cases where he had himself had to investigate

(Mr. Charles J. Wilson.)

priming, there had either been none at all, or only a very minute quantity; and in his own experience he had met with only one instance in which the priming was sufficiently large to be measured at all accurately by the calorimetric method.

The elaborate calculations made by Mr. Stromeyer (page 179) with regard to the small percentage of heat unaccounted for seemed to him to be hardly necessary. It was an unfortunate feature of the recent trial that the two thermometers employed were incapable of measuring the temperatures of the exit gases; and there was therefore obviously a certain error in the calculation. Under these circumstances he thought it was not worth while to endeavour to draw any deduction from deck-sweepings; and in any case he should be unable to recognise deck-sweepings as a sample of anything in particular. From the mere fact that the deck-sweepings were black, it would be an error to assume that they were entirely carbon. Nor as to the extent of priming could he follow the curious inference which seemed to be drawn (page 181) from the small increase in the amount of salt in the boiler; any such increase he believed had no bearing upon the matter of priming.

Mr. G. S. YOUNG enquired how the samples of steam were taken from the steam-pipe in the test for priming. It might seem at first sight quite as simple as to draw off a sample from a cask of liquor; but it was not so simple to draw off a true sample of mixed water and steam travelling at 100 feet per second along a steam-pipe. If the opening was simply in the side of the pipe, the momentum of the priming water would be so great at 100 feet per second that it would shoot right past the orifice, and the pure steam alone would pass out into the condensing apparatus. If on the other hand there was an elbow projecting inside the steam-pipe, and the elbow was turned to face the current of mixed water and steam, even then, unless the velocity within that small elbow coincided exactly with the velocity at which the mixture of steam and water was passing along the main steam-pipe, there would not be a true sample taken; because the momentum of the water being greater than that of the steam, the sample would contain a larger quantity of water and a smaller

quantity of steam than represented their true proportion in the steam-pipe. Under those circumstances he thought it would be difficult to draw any absolute conclusion from such observations. They would indeed be comparable one with another, provided the method of taking was equal in all cases; but he thought they did not represent in any case the actual amount of priming. A comparison of the analysis of the water in the hot-well with that in the boiler, as suggested by himself at a previous meeting (Proceedings 1890, page 272), he was still of opinion was the best method of obtaining an actual measure of the quantity of priming.

With regard to the condenser, there seemed no reason to doubt that the circulating water, being admitted into the top of the central chamber between the two nests of tubes, flowed outwards along the top compartment in either half of the condenser, and then turned round at the outer end and flowed inwards through the middle compartment of the same half; but on reaching the central chamber it seemed to him probable that it would not turn round again and flow outwards through the bottom compartment of the same half, but would shoot across the central chamber and flow outwards through the bottom compartment of the other half of the condenser. The consequence would be that the current through one half of the condenser would interfere with that through the other half, and the condensing surface in one half or the other would not be doing its proper share of work. From the experience he had had with many surface condensers, he had found that if two things were properly attended to there was not much fear of a bad vacuum, assuming that there was sufficient condensing surface, a sufficient quantity of circulating water, and a sufficient capacity of air-pump. The first point to be attended to was to distribute the steam horizontally over the whole surface in the upper part of the condenser, and to allow it to fall by gravitation to the bottom: not using any of the momentum given to the steam in its passage into the condenser to drive it down to the bottom, but using its whole momentum to spread it horizontally and uniformly over the whole of the top condensing surfaces. Any one who had noticed a feather falling in a vacuum within the exhausted bell-glass of an air-pump

(Mr. G. S. Young.)

would understand how the steam would drop to the bottom of the condenser readily enough by its own weight. But if the steam was blown down to the bottom of the condenser without in its passage having been in contact with sufficient cooling surface to condense it, there would be a vapour of undesirable weight lying at the bottom, which would not be condensed until it was lifted up into contact with other parts of the cooling surface by a fresh volume of incoming steam ; and there would thus be a higher pressure in the condenser. The other point to be attended to was the distribution of the circulating water so that it should travel uniformly over the whole of the condensing surface. It seemed obvious that, if the steam was properly distributed over the whole of the outside surface, and the water over the whole of the inside surface, nothing could be done in either respect for rendering the condenser more efficient. Both of these conditions could easily be obtained by fitting guide plates to direct the flow of both the steam and the water. Looking at the two ribs projecting downwards from the inside of the top of each half of the condenser in Fig. 18, Plate 21, it appeared to him they would have the effect of preventing the steam from spreading laterally over the whole surface of the tubes. With such an arrangement of condenser it seemed to him it would naturally be expected to find that there was a large amount of surface inoperative, partly on account of the water not being uniformly circulated, and partly also on account of the steam being directed downwards and reaching the bottom of the condenser before it was condensed. The steam would indeed have to be buoyed up before it would reach the other portions of the condensing surface.

Mr. ROBERT BRUCE noticed in the diagram of boiler pressure, Fig. 6, Plate 13, a drop of about 27 lbs. between one and two o'clock, corresponding with the time when the engine was slowed down. It was not explained in the report whether or not that drop was due to the fire-doors being opened, and the cold air rushing right through from the fans and cooling down the boilers. In dealing with manœuvring ships it was an important point, as was well known, to have a complete control of the evaporation ; and it was evident

that if, as he supposed, the doors were opened when the boilers cooled down, there was no possibility of having such control. The temperature of the escaping gases had been referred to, and the value of the heat carried away by them could be realized. If the air going into the furnace could be heated up to perhaps 200° Fahr. above atmospheric temperature, he calculated that it would be equivalent to a recovery of 870 heat-units per lb. of fuel. The heating of the air he had alluded to in the discussion upon Mr. Blechynden's paper read at Liverpool (Proceedings 1891, page 369); and in connection with the two new steamers now mentioned (page 169) as having recently been ordered, he would strongly recommend a study of the examples of forced draught given in that paper (1891, page 336), which he thought would be found of considerable advantage in working the new steamers.

Professor KENNEDY, Vice-President, said the point raised by Sir Frederick Bramwell (page 165)—whether the steam consumption of the auxiliary engines ought not to be included with that of the main engines, because the latter could not get on without the former—was a matter about which there might perhaps be a difference of opinion. There was no doubt that the steam consumption for the auxiliary engines was quite essential, and from that point of view the whole steam consumption had been given in the report; but as the auxiliary engines used about four times as much steam per indicated horse-power as the main engines, it was perhaps hardly fair to the latter, regarded as machines in themselves, to debit them with that large amount of steam: so that he thought the Committee were justified in giving the figures both ways, as they stood in the report.

Although Mr. Cochrane had not attended the meetings of the Committee, it should be mentioned that he had rendered them great assistance by the care with which he had examined the successive reports before they were issued to the members, and had worked out the calculations independently, and had thereby found out several arithmetical and other discrepancies, which had consequently been rectified.

(Professor Kennedy.)

The brief remarks (page 171) of such a veteran in marine work as Dr. Kirk were particularly welcome, as showing how cordially he concurred in the importance of separating the efficiency of the boiler from that of the engine. It had taken a long time to convince some marine engineers that these were two different things; but surely there should not now remain any doubts upon this point.

An interesting point had been raised by Mr. Harris (page 173) about the quantity of coal on the fires at the beginning and end of the trial. It was of course physically altogether out of the question to draw the fires at the beginning and end of a trial of this kind. The best way therefore to get rid of the error was naturally to make the trial as long as possible; and all these trials had been so long that he thought, even if they had been carelessly made, the error must have been practically eliminated. In the present instance the trial lasted only nine hours, and therefore was not so long as the previous trials had been. On a former occasion (Proceedings 1889, page 252) he had given the method followed for endeavouring to secure the same value of the fires at the starting and at the end of the trial. The straightness or otherwise of the line representing the coal consumption—like that marked “total fuel consumption” in Fig. 4, Plate 12—was really the best measure of whether there was any difference between the beginning and the end of the trial. As a matter of fact in this particular trial the fuel was put on the fire as hard as ever it could be from the beginning to the end; and if there had been any slackness of firing the boiler pressure would have gone down. Very generally in similar trials the line representing the coal consumption was something like that sketched in Fig. 24, Plate 24, the time being plotted horizontally and the consumption vertically, in the same way as was done in Fig. 4. It was found that after starting the trial, the steam probably having been allowed to drop and the fires to get a little low, the coal consumption line rose at a rather steep inclination from A to B, Fig. 24, and then from B it remained practically straight and less steep. At C, towards the end of the trial, if the plan were followed which he thought most engineers adopted of allowing the boiler pressure to fall, a nearly horizontal line was obtained from C to the very end

at D. In such cases he had over and over again found that, if a straight line were drawn from the starting point at A to the end at D—that is, if the whole coal consumption were taken over the whole time—the mean line AD was parallel to the straight portion BC of the actual line: showing that the average rate of consumption over the whole trial was the same as that which existed through the straight part BC of the actual line. By this mode of procedure therefore at the beginning and at the end he thought that in a carefully conducted trial of sufficient duration it was possible practically to eliminate errors due to the difference between the amount of fuel on the fires at the beginning and at the end. Certainly the error was less than would be due to the unavoidable irregularities consequent on any attempt to draw fires at start and finish in the stoke-holds of a steamer. But he fully recognised the fact pointed out by Mr. Harris that a running start and finish were liable on a short trial to lead to considerable errors; and in any case the greatest care was of course essential.

In connection with Mr. Rowan's remarks (page 177), he had further understood from him that, by the alteration of cut-off which he recommended, not merely had he obtained a greater speed and a greater power, but also the increase of power had been in a larger ratio than the increase of speed. This was a matter of such interest that he hoped Mr. Rowan would be able to give the figures of the actual increase both in speed and in power, and also to explain the alteration of cut-off by which so important a result was obtained. [See pages 196-7.]

The balancing of the heat account by aid of the deck-sweepings (page 179) he supposed was hardly intended by Mr. Stromeyer to be taken seriously. In certain other trials which he had himself conducted with the greatest care, he had found that he had accounted for everything to within about 3 per cent. But from this very fact he had felt great doubts whether he was right. At any rate in an ordinary marine boiler he was sure that the losses by radiation were much more than 3 per cent.—more nearly three times as much in ordinary cases. Certainly therefore the heat account ought not to balance up to 100 per cent. without allowance for radiation &c.; and

(Professor Kennedy.)

the fact that Mr. Stromeyer's approximations came out in such a fashion seemed to him to carry with it a proof that they must be erroneous.

The important question of priming had very properly been raised by Mr. Willans (page 182) and subsequent speakers. This was really a subject which he suggested might well be taken up by the Research Committee, and its investigation would probably not occupy a long time. On a former occasion it had been suggested by Mr. Young (Proceedings 1890, page 272) that the saltiness of the water in the hot-well might be assumed to represent fairly that of the condensed steam; and it was possible that the extent of priming might be determined by that means. He was very sorry that he had omitted to avail himself of that suggestion in the present trial. The question had also been raised, how far it was possible to sample the steam correctly. Besides the Barrus calorimeter, which he presumed was the apparatus alluded to by Mr. Willans (page 182) for dealing with small amounts of superheating, there were also various other contrivances for estimating the extent of priming; but all of them involved certain assumptions, and most of them involved the particular assumption of the accuracy of a sample obtained of the steam or of the water, which to begin with was a pretty big assumption. By means however of comparing several methods with one another, all being applied to the same boiler at the same time, he thought a result might be arrived at of some value; and he hoped the Committee might be able to undertake these experiments.

In reply to Mr. Young's enquiry (page 188) as to how the samples of steam were collected in the test for priming, he had to say that it was by an elbow pipe projecting into the steam pipe and facing the current of steam.

In reference to Mr. Cochrane's remark as to the calorific value of hydrogen (page 167), the value he had used in the present trial was the same that he had given in the reply to the discussion upon the previous trial (Proceedings 1891, page 287); and the value of Joule's equivalent had been taken throughout as 772 foot-lbs. per heat unit.

In the "Iona" it would be remembered that the jacket of the high-pressure cylinder was itself surrounded by steam of lower pressure in a receiver, so that the jacket served more or less to transmit heat both to inside and to outside; and he had made some remarks on this in the discussion upon the "Iona" trial (Proceedings 1891, page 284). In the "Ville de Douvres" however the condition was so far different that the high-pressure cylinder itself without a jacket was here enclosed in receiver steam (page 176); and he could not but think that this must detract considerably from the steam economy. The use of jackets he understood had been given up because of the additional weight which they entailed.

The reduction of steam pressure referred to by Mr. Bruce (page 190) was caused by the forced draught being stopped for a few minutes, and not by the opening of the fire-doors.

He desired to express the regret of every one who had taken any part in the trials that Mr. Edwards' health had not allowed him to be with them in the last two trials. Any regret felt by Mr. Edwards himself that he had not been present was not half so great as the regret of every one who had had the chance of working with him in any of the trials.

The members of the Institution, he desired to add, were greatly indebted to the Belgian Government, to Mr. Kraft, and to the Société Cockerill, not only for placing at their disposal the steamer and all its machinery, but for the cordial and kind way in which they had helped the trial. In the same connection there were also two other names that ought to be mentioned, which had not been specially referred to. The work that had been so frequently done in earlier trials by Mr. Ashcroft, in seeing that everything was got ready and into proper order before the trial came off, had on the present occasion been taken up by his friend Mr. H. R. J. Burstall, a member of the Institution. It was no less due to Mr. Ewen to say that a great deal of trouble and care had been taken by him in the collation and preparation and arithmetical working out of the large mass of figures contained in the report; and the fact that he happened to be one of the staff of the Institution was no reason why they should not recognise the extreme care he had bestowed upon the work. In

(Professor Kennedy.)

conclusion he thanked the Members for the reception given to the work of the Committee; and he hoped it might turn out that engineers in general, and shipowners and marine engineers in particular, would follow it up by making trials on their own account now that they knew that the trials were quite practicable and would yield results of such great practical value.

The PRESIDENT said that, although he had already invited the Members to pass a formal vote of thanks to all to whom they were specially indebted, he thought they ought not to lose the opportunity afforded by Mr. Kraft's presence for presenting to him a cordial and unanimous vote of thanks for the help he had given in the course of this investigation. He hoped that Mr. Kraft would understand how greatly his kindness was appreciated; and he trusted that no remarks which had been made respecting the construction of the engines would be otherwise than agreeable to him.

Mr. JAMES ROWAN sent the indicator diagrams shown in Figs. 19 to 23, Plates 22 to 24, which he had subsequently taken as offered (page 177), in illustration and confirmation of the power gained by earlier cut-off in the low-pressure cylinder. These diagrams were taken from the engines of the paddle steamer "Mercury," in the course of one of her regular trips between Prince's Pier, Greenock, and Rothesay on the Firth of Clyde. The cylinders were 33 inches and 62 inches diameter with 60 inches stroke. The diagrams were taken on the afternoon of Tuesday 5th July: first with the low-pressure valve-gear linked up to the extent of $1\frac{1}{2}$ inch distance of the link block in the slot from the position of full gear, causing the low-pressure valve to cut off at 37.8 inches or 63 per cent. of the stroke; and ten minutes later with the low-pressure link in full gear, cutting off at 41.64 inches or 69.4 per cent. of the stroke. On both occasions the high-pressure link was kept in full gear, cutting off at 44.7 inches or $74\frac{1}{2}$ per

cent. of the stroke. Under both conditions the revolutions were counted for five minutes. The boiler pressure was 110 lbs. per square inch above atmosphere, and the condenser vacuum 26 inches of mercury or 12·8 lbs. per square inch below atmosphere. The throttle-valve was kept full open all the time. The following were the different results obtained in the two modes of working:—

	Full Gear.	Linked up.
Receiver Pressure by gauge, lbs. per square inch above atmosphere	15½	20
Revolutions per minute, mean of five minutes .	51·8	53·6
Indicated horse-power, high-pressure cylinder .	782	748
" " low-pressure " "	918	1,069
" " total	<u>1,700</u>	<u>1,817</u>
Weight in lbs. of Steam used per revolution, measured at pressure of 71 lbs. per square inch above atmosphere	9·74	9·84
Work done per lb. weight of steam, in ft.-lbs. .	111,130	113,700

Hence the increased work done per lb. weight of steam amounted to 2,570 ft.-lbs.; or 2·31 per cent. increase of work was obtained by linking up the low-pressure valve-gear. The great gain was the increase in revolutions, which increased the speed of the vessel from 17 up to 17½ knots; and the net increase in total horse-power obtained was 6·88 per cent.

*Trial of the "Ville de Douvres".**Arrangement of Water - Meters.* Fig. 1. *Plan.*

Fig. 2.

Front Elevation.

Fig. 3.

*Side Elevation.**Mechanical Engineers 1892.**Scale $\frac{1}{30}^{\text{th}}$*

Inches 12 6 0 1 2 3 4 5 6 Feet

*Trial of the "Ville de Douvres."*Fig 4. *Total Fuel, Water, and Revolutions;
and Temperature of Feed-Water.*

I.H.P. "Ville de Douvres." Fig. 5. Total Indicated Horse-Power. I.H.P.

MARINE-ENGINE TRIALS. Plate 14.

"Ville de Douvres" Indicator Diagrams, Set 16.

Boiler Pressure 100·8 lbs. Revs. 37·7 per min. Total I.H.P. 2998.

Fig. 9. High-pressure cylinder: I.H.P. 1488.

Fig. 10. Low-pressure cylinder: I.H.P. 1510.

*Trial of the "Ville de Douvres."*Fig. 11. *Mean Indicator Diagrams.*

MARINE-ENGINE TRIALS.

Plate 16.

Cylinders of the "Ville de Douvres."

Fig 12. Longitudinal Section.

Mechanical Engineers 1892.

Scale $\frac{1}{36}^{\text{th}}$

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

Plate 16.

MARINE-ENGINE TRIALS.

Plate 17.

Cylinders of the "Ville de Douvres."

Fig 13. Sectional Plan.

Mechanical Engineers 1892.

Scale $\frac{1}{36}$ in

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

Plate 17.

MARINE-ENGINE TRIALS.

Plate 18.

Boilers of the "Ville de Douvres."

Fig. 14. *End Elevation and Transverse Section.*

Fig. 15. *Longitudinal Section.*

Scale 1/48th

Inches 12 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

Mechanical Engineers 1892.

Plate 18.

MARINE-ENGINE TRIALS.

Plate 19.

"Ville de Douvres".

Fig. 16. *General Arrangement of Engines and Boilers.*

Mechanical Engineers 1892.

Scale $\frac{1}{120}$ in

Plate 19.

MARINE-ENGINE TRIALS.

"Ville de Douvres."

Fig. 17. *Condenser and Air-pump.*

Plate 20.

MARINE - ENGINE TRIALS.

Plate 21.

"Ville de Douvres."

Fig. 18. Transverse Section of Condenser.

"Mercury" Indicator Diagrams.

MARINE - ENGINE TRIALS.

Plate 24.

Fig. 23. "Mercury"
Expansion of Indicator Diagrams,
Plates 22 and 23.

VV volume of Steam
converted into lbs. weight.

Dotted lines, low-pressure gear
linked up.

Full lines, full gear.

Fig. 24.
Coal Consumption.